(b) In terms of bonding, explain the meaning of the term *complex*.

.....

.....

.....

.....

(2)

(c) Identify **one** species from the following list that does **not** act as a ligand. Explain your answer.

H_2 O^{2-} O_2 CO

Not a ligand.....

Explanation .....

(2)

(d) The element palladium is in the d block of the Periodic Table. Consider the following palladium compound which contains the sulfate ion.

$[Pd(NH_3)_4]SO_4$

(i) Give the oxidation state of palladium in this compound.

.....

(1)

(ii) Give the names of two possible shapes for the complex palladium ion in this compound.

Shape 1 .....

Shape 2 .....

(2)
(Total 9 marks)

Mark schemes

1

(a) Orange dichromate

Allow max 2 for three correct colours not identified to species but in correct order

1

Changes to purple / green / ruby / red-violet / violet Chromium(III)

(Note green complex can be $[Cr(H_2O)_5Cl]^{2+}$ etc)

Do not allow green with another colour

1

That changes further to blue Chromium(II)

Allow max 1 for two correct colours not identified but in correct order

1

$[Cr_2O_7]^{2-} + 14H^+ + 3Zn \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

$2Cr^{3+} + Zn \rightarrow 2Cr^{2+} + Zn^{2+}$ /

Ignore any further reduction of Cr^{2+}

1

$[Cr_2O_7]^{2-} + 14H^+ + 4Zn \rightarrow 2Cr^{2+} + 4Zn^{2+} + 7H_2O$

Ignore additional steps e.g. formation of CrO_4^{2-}

1

(b) Green precipitate

1

(Dissolves to form a) green solution

Solution can be implied if 'dissolves' stated

1

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

Penalise $Cr(OH)_3$ once only

1

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

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

Allow formation of $[Cr(H_2O)_2(OH)_4]^-$ and $[Cr(H_2O)(OH)_5]^{2-}$ in balanced equations

Ignore state symbols, mark independently

1

(c) (ligand) substitution / replacement / exchange

Allow nucleophilic substitution

1

The energy levels/gaps of the d electrons are different (for each complex)

Ignore any reference to emission of light

1

So a different wavelength/frequency/colour/energy of light is absorbed (when d electrons are excited)

OR light is absorbed and a different wavelength/frequency/colour/energy (of light) is transmitted/reflected

1

(d) *E* O_2 (/ H_2O) > *E* Cr^{3+} (/ Cr^{2+}) / e.m.f = 1.67 V

Allow E(cell) = 1.67

1

So Cr^{2+} ions are oxidised by oxygen/air

Allow any equation of the form:

$Cr^{2+} + O_2 \rightarrow Cr^{3+}$

1

With $[Cr(H_2O)_6]^{2+}$ get $CrCO_3$

If named must be chromium(II) carbonate

1

with $[Cr(H_2O)_6]^{3+}$ get $Cr(H_2O)_3(OH)_3$ / $Cr(OH)_3$

Allow 0 to 3 waters in the complex

1

and CO_2

Can score M3, M4, M5 in equations even if unbalanced

1

Cr(III) differs from Cr(II) because it is acidic / forms H^+ ions

1

because Cr^{3+} ion polarises water

Ignore charge/size ratio and mass/charge

1

[19]

2 (a) *For reactions 1 to 3 must show complex ions as reactants and products*

Take care to look for possible identification on flow chart

Reaction 1

ammonia solution

1

W is $[Co(NH_3)_6]^{2+}$

1

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

Correct equation scores all 3 marks

1

Reaction 2

Allow oxygen, Do not allow air

H_2O_2

1

X is $[Co(NH_3)_6]^{3+}$

1

$2[Co(NH_3)_6]^{2+} + H_2O_2 \rightarrow 2[Co(NH_3)_6]^{3+} + 2OH^-$

Allow $2[Co(NH_3)_6]^{2+} + ½O_2 + H_2O \rightarrow 2[Co(NH_3)_6]^{3+} + 2OH^-$

Correct equations score all 3 marks

1

Reaction 3

HCl

Do not allow Cl^- *but mark on*

1

Y is $[CoCl_4]^{2-}$

1

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

Correct equation scores previous mark

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

This equation scores all three marks

1

Reaction 4

Na_2CO_3 Or $NaOH/NH_3$

Do not allow $CaCO_3$ *as a reagent but mark on*

1

Z is $CoCO_3$ $Co(OH)_2/Co(H_2O)_4(OH)_2$

1

$[Co(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow CoCO_3 + 6H_2O$ $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(H_2O)_4(OH)_2 + 2H_2O$ etc

Allow waters to stay co-ordinated to Co. This mark also previous mark

Or $[Co(H_2O)_6]^{2+} + Na_2CO_3 \rightarrow CoCO_3 + 6H_2O + 2Na^+$

Allow $Co^{2+} + CO_3^{2-} \rightarrow CoCO_3$

1

(b) $SO_3^{2-} + ½O_2 \rightarrow SO_4^{2-}$

Allow multiples

1

The activation energy is lower (for the catalysed route)

Or Co^{3+} attracts SO_3^{2-}/Co^{2+} attracts SO_3^{2-}/oppositely charged ions attract

1

$½O_2 + 2Co^{2+} + 2H^+ \rightarrow H_2O + 2Co^{3+}$

1

$2Co^{3+} + SO_3^{2-} + H_2O \rightarrow 2Co^{2+} + SO_4^{2-} + 2H^+$

Allow these equations in either order

1

[16]

3 (a) To reduce any Fe^{3+} ions to Fe^{2+} ions

Allow 'to ensure that all of the iron present is in the form of Fe^{2+} ions' or 'to ensure that no Fe^{3+} ions are present'.

1

(b) Zinc would react with MnO_4^- / Fe^{3+} produced in titration

Do not allow 'would increase titre value'.

Do not allow 'zinc would react' without further qualification.

1

[2]

4 (a) (i) Flask with side arm

1

Buchner funnel and horizontal filter paper

Allow Hirsch funnel and horizontal filter paper.

Do not allow standard Y-shaped funnel.

If there is not a clear air-tight seal (labelled or drawn) between the funnel and the flask maximum 1 mark.

1

(ii) M_r $KMnO_4$ = 158(.0)

1

Mass = 0.225 × 158 / 3 = 11.9 (g)

Lose M2 if no working shown.

Allow consequential mark on an incorrect M_r for $KMnO_4$

1

Precision mark: three significant figures

Allow if mass incorrect.

1

(iii) (Unpleasant) taste

Ignore smell.

1

(b) Difficult to see meniscus / line on graduated flask

Do not allow reference to over filling.

1

[7]

5 (a) Manganate would oxidise / react with $\underline{Cl}^-$

1

Because $E^\ominus$ for MnO_4^- is more positive than that for Cl^2 / 1.51 – 1.36 = +0.15 (V)

Must refer to data from the table for M2.

1

(b) Moles of H^+ = 25 × 0.0200 × 8 / 1000 = 4.00 × 10^{-3}

1

Moles of H_2SO_4 = 2.00 × 10^{-3} (4.00 × 10^{-3} / 2)

Allow consequential marking on incorrect moles of H^+

1

Volume H_2SO_4 = 4.00 (cm^3) (2.00 × 10^{-3} × 1000 / 0.500)

Allow consequential marking on incorrect moles of H_2SO_4

Accept 4 cm^3.

8 cm^3 scores 2 marks.

Do not penalise precision.

Correct answer without working scores M3 only.

1

(c) (i) $MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$

Allow multiples, including fractions.

Ignore state symbols.

1

(ii) Can't see end point due to brown colour

1

Larger titre (than expected)

Allow the idea that with two reactions can't make use of titre in calculations.

Do not allow 'an inaccurate result' without qualification.

1

(d) Solution (very) dilute / lots of water

1

[9]

6 (a) (i) Correctly plots all points (± one square) and draws straight line of best fit

Lose this mark if the candidate's line is doubled or kinked.

Lose this mark if the line does not pass within one square of the origin, extending the line if necessary.

1

Plotted points cover over half of grid

1

(ii) 0.046 ± 0.002 (mol dm^{-3})

1

0.088 to 0.096 (mol dm^{-3})

Allow M1 × 2

Allow two marks for correct answer.

Answer must be to at least two significant figures.

1

(iii) Total volume = (100 × 0.1) / 0.04 = 250 (cm^3)

Allow any correct alternative method of working.

1

Therefore add 150 cm^3

Correct answer without working scores M2 only.

1

(b) Iron needed for haemoglobin / for red blood cells / to carry oxygen around the body

Accept well-water may contain eg Ca^{2+} ions / dissolved minerals that are good for bones / teeth etc.

1

[7]

7 (a) Stop the formation of MnO_2 / Ensures all MnO_4^- reacts to form Mn^{2+} / becomes colourless

1

(b) Weak acid / Does not supply sufficient H^+

1

(c) It is self-indicating / Purple to colourless end-point or vice versa

If colours mentioned they must be correct.

1

[3]

8

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

For all species correct / moles and species correct but charge incorrect

1

For balanced equation including all charges (also scores first mark)

1

(b) Manganate(VII) ions are coloured (purple)

1

All other reactants and products are **not** coloured (or too faintly coloured to detect)

Allow (all) other species are colourless

Allow Mn^{2+} are colourless / becomes colourless / pale pink

1

(c) The catalyst for the reaction is a reaction product

1

Reaction starts off slowly / gradient shallow

1

Then gets faster/rate increases / gradient increases

Allow concentration of MnO_4^- decreases faster / falls rapidly

1

(d) Mn^{2+} ions

Allow Mn^{3+} ions

1

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

Allow multiples

1

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

1

[10]

9

(a) Variable oxidation state

1

eg Fe(II) and Fe (III)

Any correctly identified pair

Allow two formulae showing complexes with different oxidation states even if oxidation state not given

1

(Characteristic) colour (of complexes)

1

eg Cu^{2+}(aq) / $[Cu(H_2O)_6]^{2+}$ is blue

Any correct ion with colour scores M3 and M4

Must show (aq) or ligands OR identified coloured compound e.g. $CoCO_3$)

1

(b) Tetrahedral

1

$[CuCl_4]^{2-}$ / $[CoCl_4]^{2-}$

Any correct complex

(Note charges must be correct)

1

Square planar

1

$(NH_3)_2PtCl_2$

Any correct complex

1

Linear

Do not allow linear planar

1

$[Ag(NH_3)_2]^+$

$[AgCl_2]^-$ etc

1

(c) (i) $[Ca(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [CaEDTA]^{2-} + 6H_2O$

If equation does not show increase in number of moles of particles CE = 0/3 for (c)(ii)

If no equation, mark on

1

(ii) 2 mol of reactants form 7 mol of products

Allow more moles/species of products

Allow consequential to (c)(i)

1

Therefore disorder increases

1

Entropy increases / +ve entropy change / free-energy change is negative

1

(iii) Moles EDTA = $6.25 \times 0.0532 / 1000 = (3.325 \times 10^{-4})$

1

Moles of Ca^{2+} in 1 dm^3 = $3.325 \times 10^{-4} \times 1000 / 150 = (2.217 \times 10^{-3})$

Mark is for M1 × 1000 / 150 ***OR*** *M1 × 74.1*

If ratio of Ca^{2+} : EDTA is wrong or 1000 / 150 is wrong, CE and can score M1 only

This applies to the alternative

1

Mass of $Ca(OH)_2$ = $2.217 \times 10^{-3} \times 74.1 = 0.164$ g

M1 × 74.1 × 1000 / 150

Answer expressed to 3 sig figs or better

Must give unit to score mark

Allow 0.164 to 0.165

1

[17]

10 (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 <u>dark/deep blue solution</u>

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

<u>Green precipitate</u> 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 <u>brown solid</u>

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 + $4H^+ \longrightarrow 2H_2O$

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]

11 (a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$

allow [He] $2s^2$. or [Ne] $3s^2$.or [Ar]$3d^{10}$

1

d sub-shell / shell / orbitals / sub-level full (or not partially full)

can only score M2 if d^{10} in M1 correct

allow 'full d orbital' if d^{10} in M1

do not allow d block

1

(b) atom or ion or transition metal bonded to / surrounded by one or more ligands

Allow Lewis base instead of ligand

1

by co–ordinate / dative (covalent) bonds / donation of an electron pair

can only score M2 if M1 correct

1

(c) H_2 / hydrogen

do not allow H

1

no lone / spare / non-bonded pair of electrons

only score M2 if M1 correct or give 'H' in M1

1

(d) (i) +2 or 2+ or Pd^{2+} or II or +II or II+ or two or two plus

1

(ii) tetrahedral

these shapes can be in any order

1

square planar

allow phonetic spelling e.g. tetrahydral

1

[9]