M1.(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

Slope / 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]

M2.(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]

M3.(a) Negative ions repel one another

1

(b) Positive ions attract 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]

M4.(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]

M5.(a) Cobalt has variable oxidation states

Allow exists as Co(II) and Co(III)

1

(It can act as an intermediate that) lowers the activation energy

Allow (alternative route with) lower E_a

1

$CH_3CHO + 2Co^{3+} + H_2O \rightarrow CH_3COOH + 2Co^{2+} + 2H^+$

Allow multiples; allow molecular formulae

Allow equations with H_3O+

1

$\frac{1}{2}O_2 + 2Co^{2+} + 2H^+ \rightarrow 2Co^{3+} + H_2O$

1

(b) (i) $[Co(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$

Do not allow en in equation, allow $C_2H_8N_2$

1

The number of particles increases / changes from 4 to 7

Can score M2 and M3 even if equation incorrect or missing provided number of particles increases

1

So the entropy change is positive / disorder increases / entropy increases

1

(ii) Minimum for **M1** is 3 bidentate ligands bonded to Co

Ignore all charges for M1 and M3 but penalise charges on any ligand in M2

1

Ligands need not have any atoms shown but diagram must show 6 bonds from ligands to Co, 2 from each ligand

Minimum for **M2** is one ligand identified as H_2N-----NH_2

Allow linkage as −C−C− or just a line.

1

Minimum for **M3** is one bidentate ligand showing two arrows from separate nitrogens to cobalt

1

(c) Moles of cobalt = (50 × 0.203) / 1000 = 0.01015 mol

Allow 0.0101 to 0.0102

1

Moles of AgCl = 4.22/143.4 = 0.0294

Allow 0.029

*If not AgCl (eg $AgCl_2$ or $AgNO_3$), lose this mark and can only score **M1, M4** and **M5***

1

Ratio = Cl^- to Co = 2.9 : 1

*Do not allow 3 : 1 if this is the only answer but if 2.9:1 seen somewhere in answer credit this as **M3***

1

$[Co(NH_3)_6]Cl_3$ (square brackets not essential)

1

Difference due to incomplete oxidation in the preparation

Allow incomplete reaction.

Allow formation $[Co(NH_3)_5Cl]Cl_2$ etc.

Some chloride ions act as ligands / replace NH_3 in complex.

Do not allow 'impure sample' or reference to practical deficiencies

1

[15]

M6.(a) Stoppered flask or similar with side arm

Allow gas outlet through stopper.

1

Calibrated container for collection eg gas syringe

Allow collection over water, but must use calibrated vessel for collection.

Lose 1 mark if apparatus is not gas tight.

1

(b) Plot a graph of 'volume (of gas)' against 'time'

1

Determine the slope (gradient) at the beginning

1

(c) Repeat with same volume **or** concentration of hydrogen peroxide and at the same temperature

Ignore references to results.

Do not allow 'keep everything the same' or words to that effect. Must mention volume or concentration and temperature.

1

Add cobalt(II) chloride to one experiment

1

[6]

M1.(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]

M2. (a) $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$

1

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

1

two negative ions repel / lead to reaction that is slow / lead to reaction that has high E_a

1

iron able to act because changes its oxidation state

allow iron has variable oxidation state

1

With iron ions have alternative route / route with lower activation energy

1

(b) (i) $[Fe(H_2O)_6]^{3+} \rightarrow [Fe(H_2O)_5OH]^{2+} + H^+$

can have H_2O on LHS and H_3O^+ on R

do not penalise further hydrolysis equations

allow high charge density

1

Fe^{3+} ion has higher charge (to size ratio) (than Fe^{2+})

1

increases polarisation of co-ordinated water / attracts O releasing an H^+ ion / weakens O–H bond

1

(ii) $Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$

or 6 mol Fe(II) react with 1 mol dichromate

If factor of 6 not used max = 3 for M2, M4 and M5

e.g. 1:1 gives ans= 8.93 to 8.98% (scores 3)

1

moles dichromate = $23.6 \times 0.218/1000 = 5.14 \times 10^{-4}$

1

moles iron = $5.14 \times 10^{-4} \times 6 = 0.00309$

M3 also scores M1

1

mass iron = $0.00309 \times 55.8 = 0.172$

Mark is for moles of iron × 55.8 conseq

Allow use of 56 for iron

1

% by mass of iron = $0.172 \times 100/0.321 = 53.7\%$

Answer must be to at least 3 sig figures allow 53.6 to 53.9

Mark is for mass of iron × 100/0.321 conseq

1

(c) brown precipitate / solid

Allow red-brown / orange solid

Not red or yellow solid

1

bubbles (of gas) / effervescence/ fizz

Allow gas evolved / given off

Do not allow just gas or CO_2 or CO_2 gas

1

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

Allow

$2[Fe(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2Fe(OH)_3 + 3CO_2 + 9H_2O$

Use of Na_2CO_3

e.g. … + $3Na_2CO_3 \rightarrow$ .. + .. + .. + $6Na^+$

1

[16]

M3. (a) Same phase/state

1

(b) Because only exist in one oxidation state

Allow do not have variable oxidation states

1

(c) $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$

Ignore state symbols
Allow multiples

1

(d) Both (ions)have a negative charge

Or both have the same charge
Or (ions) repel each other
Do not allow both molecules have the same charge (contradiction)

1

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

1

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

1

Equations can be in any order

Positive and negative (ions)/oppositely charged (ions)

Mark independently

1

(f) Equations 1 and 2 can occur in any order

Allow idea of Fe^{3+} converted to Fe^{2+} then Fe^{2+} converted back to Fe^{3+}

1

[8]

M4. (a) Incomplete (or partially filled) d orbitals/sub-shells

Do not allow d shell

1

(b) Variable oxidation states

1

(c) (i) $[H_3N–Ag–NH_3]^+$

Allow $[Cl–Ag–Cl]^-$ or similar Cu(I) ion

Allow compounds in (i), (ii) and (iii) (eg Cl-Be-Cl)

Allow no charge shown, penalise wrong charge(s)

1

(ii) Cis platin drawn out as square planar

Allow NiX_4^{2-} etc

1

(iii) $[CuCl_4]^{2-}$ drawn out as tetrahedral ion

Or $[CoCl_4]^{2-}$ drawn out

1

(d) (i) $SO_2 + 1/2O_2 \rightarrow SO_3$

Allow multiples

Allow $SO_2 + 1/2O_2 + H_2O \rightarrow H_2SO_4$

ignore state symbols

1

(ii) In a different phase/state (from the reactants)

1

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

can be in either order

1

$V_2O_4 + 1/2O_2 \rightarrow V_2O_5$

allow multiples

1

(iv) Surface area is increased

1

By use of powder or granules or finely divided

Allow suspending/spreading out onto a mesh or support

1

(e) (i) Forms two or more co-ordinate bonds

Allow more than one co-ordinate bond or <u>donates</u> more than 1 electron pair.

Do not allow "has more than one electron pair"

Allow uses more than one atom to bond (to TM)

1

(ii) Number of product particles > Number of reactant particles

Allow molecules/entities instead of particles

Penalise incorrect numbers (should be 2→5)

1

Disorder increases or entropy increases
(or entropy change is positive)

Allow ΔG must be negative because ΔH = 0 and ΔS is +ve

1

(iii) 6

1

Cyanide strongly bound to Co (by co-ordinate/covalent bond)

1

[16]

M1. (a) Alternative route

Allow mechanism outlined
allow forms intermediate species

1

Lower activation energy

1

(b) Variable oxidation state

allow changes oxidation states

1

(c) (i) $SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4$

allow $2VO_2$ instead of V_2O_4

1

$O_2 + 2V_2O_4 \rightarrow 2V_2O_5$

1

(ii) Poison attaches to surface

Allow blocks active site/surface
Decreases surface area

1

(iii) Purify reactants

Allow remove impurities

1

[7]

M2. (a) $FeCl_3$ accepts electron pairs from water

1

Hence acts as a Lewis acid

1

$[Fe(H_2O)_6]^{3+}$ donates protons

1

Hence acts as a Bronsted-Lowry acid

1

(b) The Fe^{2+} ion has a smaller charge to size ratio

1

Hence less polarising than Fe^{3+} or less weakening effect on O-H bonds

1

(c) (i) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$

1

$V_2O_4 + O_2 \rightarrow V_2O_5$

1

(ii) Both ions are negative or ions repel

1

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

1

Balanced

1

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

1

Balanced

1

[13]

M3. (a) A catalyst in the same phase/phase as the reactants

1

(b) (i) A reaction in which a product acts as a catalyst

1

(ii) Mn^{2+} or Mn^{3+}
"Self-catalysing" not allowed

1

(c) (i) $2CO + 2NO \rightarrow 2CO_2 + N_2$

or $4CO + 2NO_2 \rightarrow 4CO_2 + N_2$
C not allowed as a product

1

Reducing agent CO

1

(ii) Pt, Pd or Rh

1

Deposited on a ceramic honeycomb or matrix or mesh or sponge

1

To increase surface area of catalyst

1

(d) (i) Reactants cannot move on surface or products not desorbed or
Active sites blocked

1

(ii) Reactants not brought together or
No increase in reactant concentration on catalyst surface or
Reactants not held long enough for a reaction to occur or
Reactant bonds not weakened

1

[10]

M4. (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]

M5. (a) effect on reaction rate: catalyst provides an alternative reaction route.;

1

with a lower E_a;

1

more molecules able to react or rate increased;

1

equilibrium: forward and backward rates changes by the same amount;

1

hence concentration of reactants and products constant or yield unchanged;

1

(b) heterogeneous: catalyst in a different phase or state to that of

the reactants;

1

active site: place where reactants adsorbed or attached or bond etc.;

1

reaction occurs or an explanation of what happens;
(allow absorbed)

1

reasons: large surface area;
reduce cost or amount of catalyst;

2

catalyst poison: lead adsorbed;
lead not desorbed or site blocked;
(lead adsorbed irreversibly scores both of these marks)

2

(c) reaction slow as: both ions negatively charged or ions repel;

1

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

2

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

2

[17]

M6.C

[1]

M1. (a) (i) Heterogeneous:- In a different phase to reactants **(1)**

Catalyst:- Increases reaction rate **(1)**

Alternative route or route described **(1)**

Lower E_a **(1)**

Unchanged at end of reaction **(1)** Max 4

(ii) Feature:- QoL Variable oxidation states shown by vanadium **(1)**

Equations $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ **(1)**

$2V_2O_4 + O_2 \rightarrow 2V_2O_5$ **(1)**

7

(b) $VO_2^+ + 4H^+ + 3e^- \rightarrow V^{2+}(aq) + 2H_2O$ **(1)**

$Zn \rightarrow Zn^{2+} + 2e^-$ (given)

$2VO_2^+ + 8H^+ + 3Zn \rightarrow 3Zn^{2+} + 2V^{2+}(aq) + 4H_2O$ **(1)**

2

Mol $KMnO_4$ = mv/1000 = 0.0200 × 38.5/1000 = 7.70×10^{-4} **(1)**

Mole ratio MnO_4^- to V(II) = 3:5 deduced

or equation

$5V^{2+} + 3MnO_4^- + 4H^+ \rightarrow 2H_2O + 3Mn^{2+} + 5VO_2^+$ **(2)**

Mol V(II) = $7.70 \times 10^{-4} \times 5/3$ **(1)** = 1.283×10^{-3}

Mass V = $1.283 \times 10^{-3} \times 50.9$ **(1)** = 0.0653 g

% V in sample = 0.06532 × 100/0.160 = 40.8 **(1)**

6

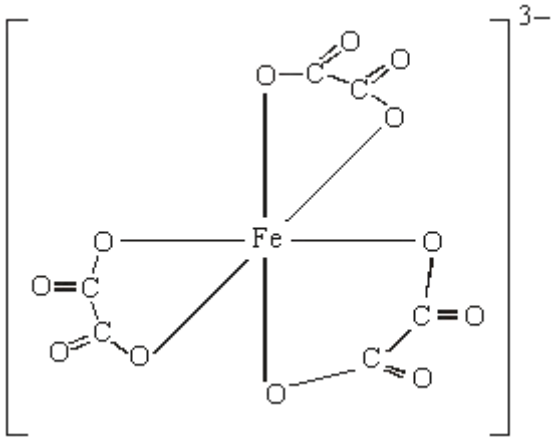
[15]

M2. (a) (i) Two **(1)** lone pair donor / electron pair donor **(1)** atoms

Allow:– forms two co-ordinate bonds **(1)**

NOT atom with two lone pairs

(ii)



(O=C not essential)

*Correct ligand structure **(1)***
penalise any error
*Six correct O–Fe bonds **(1)***
*Correct charge **(1)***
N.B. Penalise the second mark if arrow from Fe shown
N.B. Ignore charges on atoms

5

(b) (Substitution of a monodentate ligand by a) bi or multidentate ligand **(1)** giving a more stable complex **(1)** or with an increase in entropy / disorder or forming a ring / cage complex / structure (crab like)

2

(c) (i) $[AgCl_2]^-$ or $AgCl_2^-$ **(1)**

(ii) Chloride or Cl^- big or large or repel **(1)**
NOT Cl_2 or Cl^+ or Cl
Allow 'chlorine ion'

2

(d) (i) (Both) ions are negative or ions repel or High E_a **(1)**

(ii) *Meaning of the term autocatalytic:* A product of the reaction acts as a catalyst **(1)**

NOT a self catalysing reaction (0)

Catalyst: Mn^{2+} or Mn^{3+} **(1)**

(iii) Mn^{2+} converted into Mn^{n+} or Mn^{2+} oxidised **(1)**
Mn^{n+}/oxidised species then <u>oxidises/reacts with $C_2O_4^{2-}$</u> **(1)**

5

[14]

M3. (a) reactants brought together / increased concentration on surface or increased collision frequency **(1)**
reactants must be correctly orientated **(1)**
reaction on the surface **(1)**
products desorbed **(1)**
example of a catalysed reaction (not a named process) **(1)**
a suitable catalyst for this reaction **(1)**

penalise incorrect second reactions and catalysts

If absorption too weak reactants not brought together **(1)**
e.g. silver **(1)**
If adsorption too strong products not desorbed **(1)**
e.g. tungsten **(1)**

max 8

(b) Equations:

$Cr_2O_7^{2-} + 14\ H^+ + 6\ Fe^{2+} \rightarrow 6\ Fe^{3+} + 2\ Cr^{3+} + 7\ H_2O$ **(1)**
$Zn + 2\ Fe^{3+} \rightarrow Zn^{2+} + 2\ Fe^{2+}$ **(1)**

Method

Titrate measured volume solution against $K_2Cr_2O_7$ **(1)**

Reduce same volume solution with zinc **(1)**

Filter off excess zinc **(1)**

Titrate total Fe^{n+} using $K_2Cr_2O_7$ **(1)**

Percentage Fe^{3+} = 100 × (titre2 - titre1) / titre 2
or equivalent **(1)**

7

[15]

M4.D

[1]

M5. (a) High E_a: $S_2O_8^{2-}$ repels I^- **or** both ions negative **(1)**

$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ **(1)**

$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ **(1)**

N.B. Ignore additional incorrect equations

Vanadium is a transition element **or** Magnesium is not a transition element **(1)**

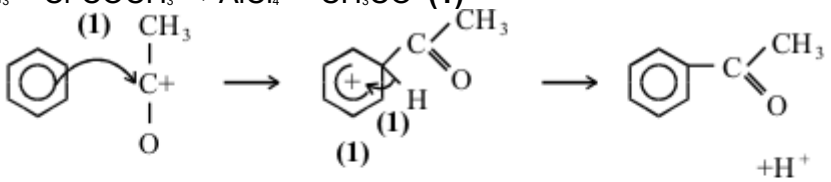
Vanadium has variable oxidation states **(1)**

Magnesium only forms Mg^{2+}, **or** has only one oxidation state **(1)**

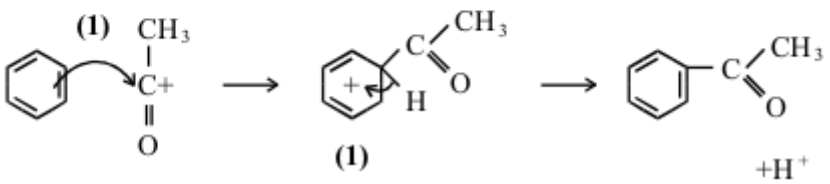
N.B. Score two marks for "Only vanadium has variable oxidation states"

6

(b) $AlCl_3 + Cl\text{-}COCH_3 \rightarrow AlCl_4^- + CH_3CO^+$ **(1)**



or



$H^+ + AlCl_4^- \rightarrow AlCl_3 + HCl$ **(1)**

Lewis acid: $AlCl_3$ accepts electron pair

N.B. penalise incorrect acyl chloride by one
N.B. penalise chloroethane by two marks i.e. first equation mark, attack on benzene mark

NH_4Cl: Not a catalyst **(1)**

$FeCl_3$: A catalyst **(1)**
has a low energy vacant shell
or has spaces or vacancies in d shell
or has a partially filled d shell
or able to accept an electron pair
or can form $FeCl_4^-$ **(1)**

9

[15]

M1.(a) <u>164.0</u>

Must be 1 decimal place

1

(b) 17.1(%) (= 28.0 × 100 / Qa)

Consequential on their (a)

Ignore precision but must be to at least 2 sig fig.

(i.e. accept 17 or 17.07)

1

(c) (i) <u>*Absorption*</u> depends on (proportional to) path length / distance travelled through solution

Do not allow size.

1

(ii) To select the colour / frequency / wavelength that is (most strongly) absorbed (by the sample)

Allow the filter is chosen to complement the colour of the solution

1

(iii) Quicker to analyse extracted samples than by titration / uses smaller volumes of solution

1

[5]

M2.(a) $\Delta E = hv$

Allow = hf

1

$v = \Delta E / h = 2.84 \times 10^{-19} / 6.63 \times 10^{-34} = 4.28 \times 10^{14}$ s^{-1} / Hz

Allow 4.3×10^{14} s^{-1} */ Hz*

Answer must be in the range:

$4.28 - 4.30 \times 10^{14}$

1

(b) (One colour of) light is absorbed (to excite the electron)

If light emitted, CE = 0

1

The remaining colour / frequency / wavelength / energy is transmitted (through the solution)

Allow light reflected is the colour that we see.

1

(c) Bigger

1

Blue light would be absorbed

OR light that has greater energy than red light would be absorbed
OR higher frequency (of light absorbed / blue light) leads to higher *ΔE*

Can only score M2 if M1 is correct.

1

(d) Any **three** from:

- (Identity of the) metal
- Charge (on the metal) / oxidation state / charge on complex
- (Identity of the) ligands
- Co-ordination number / number of ligands
- Shape

3 max

[9]

M3.(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]

M4.(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]

M1.(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]

M2.(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]

M3.(a) (i) absorbs (certain frequencies of) (white) light / photons

not absorbs white / u.v. light

1

d electrons excited / promoted

or d electrons move between levels / orbitals

d electrons can be implied elsewhere in answer

1

the colour observed is the light not absorbed / light reflected / light transmitted

allow blue light transmitted

penalise emission of light in M3

1

(ii) ΔE is the energy gained by the (excited) electrons (of Cu^{2+})

allow:

- *energy difference between orbitals / sub-shells*
- *energy of photon / light absorbed*
- *change in energy of the electrons energy lost by excited electrons*
- *energy of photon / light emitted*

1

h (Planck's) constant

1

v frequency of light (absorbed by $Cu^{2+}(aq)$)

do not allow wavelength

If energy lost / photon lost / light emitted in M1 do not penalised light emitted

1

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

note that $[CuCl_4^-]^{2-}$ is incorrect

penalise charges shown separately on the ligand and overall

penalise HCl

1

tetrahedral

1

Cl^- / Cl / chlorine too big (to fit more than 4 round Cu)

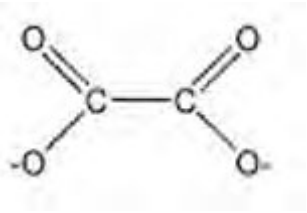
allow

water smaller than Cl^-

explanation that change in shape is due to change in co-ordination number

1

(b)



allow:

- *ion drawn with any bond angles*
- *ion in square brackets with overall / 2- charge shown outside the brackets*
- *ion with delocalised O=C–O bonds in carboxylate group(s)*

1

lone pair(s) on O^- / O

allow position of lone pair(s) shown on O in the diagram even if the diagram is incorrect.

1

(c) (i) $[Cu(H_2O)_6]^{2+} + 2C_2O_4^{2-} \rightarrow [Cu(C_2O_4)_2(H_2O)_2]^{2-} + 4H_2O$

product correct

1

equation balanced

1

6

note can only score M3 and M4 if M1 awarded or if complex in equation has 2 waters and 2 ethanedioates

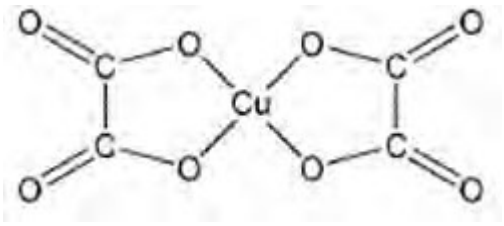
1

octahedral

If this condition is satisfied the complex can have the wrong charge(s) to allow access to M3 and M4 but not M1

1

(ii)



ignore charges

diagram must show both ethanedioates with correct bonding

ignore water

1

90°

allow 180°

mark bond angle independently but penalise if angle incorrectly labelled / indicated on diagram

1

[17]

M4.(a) Plots all of the points correctly ± one square

1

Straight line through the points is best fit

Candidate does not have to extrapolate line to the origin.

Line must pass through the origin ± 1 square.

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

Allow line that doesn't pass through the origin if one or more points are misplotted.

1

(b) $7.6 \pm 0.1 \times 10^{-2}$ (mol dm^{-3})

Do not penalise precision, but at least 2 significant figures.

1

[3]

M1. (a) (i) Ammonia

If reagent is missing or incorrect cannot score M3

1

Starts as a pink (solution)

1

Changes to a yellow/straw (solution)

Allow pale brown

Do not allow reference to a precipitate

1

(ii) (dark) brown

Do not allow pale/straw/yellow-brown (i.e. these and other shades except for dark brown)

1

(b) (i) Ruby/red-blue/purple/violet/green

Do not allow red or blue

If ppt mentioned contradiction/CE =0

1

Green

If ppt mentioned contradiction/CE =0

1

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

1

Formula of product

Can score this mark in (b) (ii)

1

(ii) $H_2O_2 + 2e^- \rightarrow 2OH^-$

1

$2[Cr(OH)_6]^{3-} + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O + 2OH^-$

Allow 1 mark out of 2 for a balanced half-equation such as $Cr(III) \rightarrow Cr(VI) + 3e^-$

or $Cr^{3+} + 4H_2O \rightarrow CrO_4^{2-} + 8H^+ + 3e^-$ *etc*

also for $2Cr(III) + 3H_2O_2 \rightarrow 2CrO_4^{2-}$ *(unbalanced)*

2

Yellow

Do not allow orange

1

(c) $2MnO_4^- + 6H^+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$

if no equation and uses given ratio can score M2, M3, M4 & M5

1

Moles MnO_4^- = (24.35/1000) × 0.0187 = $\underline{4.55 \times 10^{-4}}$

Note value must be quoted to at least 3 sig. figs.

M2 is for 4.55×10^{-4}

1

Moles H_2O_2 = (4.55×10^{-4}) $\underline{\times 5/2}$ = 1.138×10^{-3}

M3 is for × 5/2 (or 7/3)

Mark consequential on molar ratio from candidate's equation

1

Moles H_2O_2 in 5 cm^3 original

M4 is for × 10

1

= (1.138×10^{-3}) $\underline{\times 10}$ = 0.01138

Original $[H_2O_2]$ = 0.01138 $\underline{\times (1000/5)}$ = 2.28 mol dm^{-3}

(allow 2.25-2.30)

M5 is for consequentially correct answer from (answer to mark 4) × (1000/5)

Note an answer of between 2.25 and 2.30 is worth 4 marks)

If candidate uses given ratio 3/7 max 4 marks:

***M1**: Moles of MnO_4^- = $\underline{4.55 \times 10^{-4}}$*

***M2**: Moles H_2O_2 = (4.55×10^{-4}) $\underline{\times 7/3}$ = 1.0617×10^{-3}*

***M3**: Moles H_2O_2 in 5 cm^3 original*

= (1.0617×10^{-3}) × 10 = 0.01062

M4: Original $[H_2O_2]$ = 0.01062 × (1000/5) = 2.12 mol dm^{-3}

(allow 2.10 to 2.15)

1

[17]

M2. (a) $CaF_2(s) \rightarrow Ca^{2+}(g) + 2F^-(g)$

1

(b) (i) Enthalpy change for formation of 1 mol of substance

Allow heat energy change, NOT energy

1

From its elements

1

Reactants and products/all substances in their standard states

Or normal states at 298 K, 1 bar (100 kPa)

1

(ii) $Ca(s) + F_2(g) \rightarrow CaF_2(s)$

1

(iii) $\Delta H_f(CaF_2) = \Delta H_a(Ca) + 1st\ IE(Ca) + 2^{nd}\ IE(Ca) + BE(F_2) + 2 \times EA(F) - \Delta H_L(CaF_2)$

Or labelled diagram

1

$= 193 + 590 + 1150 + 158 + (2 \times -348) - 2602$

1

$= -1207\ kJ\ mol^{-1}$

Correct answer scores 3
–842 scores 2 (transfer error)
–859 scores 1 only (using one E.A.)
Units not required, wrong units lose 1 mark

1

(c) Electrostatic attraction stronger/ionic bonding stronger/attraction between ions stronger/more energy to separate ions

Molecular attraction/atoms/intermolecular forces CE=0

1

Because fluoride (ion) smaller than chloride

Do not allow F or fluorine

1

(d) (i) $\Delta H = \Delta H_L + \Sigma \Delta H_{hyd} = 2237 - 1650 + (2 \times -364)$

Can be on cycle/diagram

1

$= -141\ kJ\ mol^{-1}$

Correct answer scores 2
Units not required, wrong units lose 1 mark

1

(ii) Decreases

If ans to (d)(i) positive allow increases

1

Reaction exothermic/ΔH –ve

If (d)(i) +ve allow endothermic/ΔH + ve

1

(Equilibrium) shifts to left/backwards
(as temperature rises)/equilibrium
opposes the change

If (d) (i) +ve allow shifts to right/forwards/equilibrium opposes the change

If no answer to (d) (i) assume –ve ΔH used
If effect deduced incorrectly from any ΔH CE = 0 for these 3 marks

1

(e) u.v. absorbed: electrons/they move to higher energy (levels)/electrons excited

1

visible light given out: electrons/they fall back down/move to lower energy (levels)

Must refer to absorbing u.v. NOT visible light or this must be implied.

1

[17]

M3. (a) Partially filled/incomplete d sub-shell/orbital/shell

Ignore reference to f orbitals

*Do **not** allow d block*

*Do **not** allow half-filled d orbitals*

1

(b) Has ligand(s)

Allow molecules/ions with lone pairs

1

linked by co-ordinate bonds

Allow dative/donation of lone pair

1

(c) (Blue) light is absorbed (from incident white light)

1

Due to electrons moving to higher levels/electrons excited

Allow d → d transitions

1

Red light (that) remains (is transmitted)/light that remains (transmitted light) is the colour observed

Allow red light reflected

1

(d) (i) Circle round any O^-

List principle

1

Circle round either N

1

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

Allow missing square brackets
Ignore state symbols

1

(iii) Increase in entropy/ΔS positive

Or increase in disorder

1

Because 2 mol (of particles/molecules/species/entities) form 7 mol

Allow 'increase in number' as stated in words or as shown by any numbers deduced correctly from an incorrect equation

Do not allow increase in ions/atoms

1

(e) (i) Co-ordinate/dative/dative covalent bond

Allow pair of electrons donated by nitrogen/ligand
Do not allow pair of electrons donated from Iron/Fe

1

Covalent bond

Shared electron pair

1

(ii) Transport of oxygen/O_2

Allow any statement that implies oxygen carried (around the body)

Do not allow transport of carbon dioxide (CO_2). This also contradicts the mark (list principle)

1

(iii) Because it bonds to the iron/haemoglobin

Allow blocks site
/CO has greater affinity for haemoglobin
/carboxyhaemoglobin more stable than oxyhaemoglobin

1

Displaces oxygen

Or prevents transport of oxygen
QoL

1

[16]

M1. (a) $[Co(H_2O)_6]^{2+}$

1

octahedral

Only allow if species has 6 ligands
but allow if M1 not given because charge missing

1

(b) $CoCO_3$

Mark independently

1

Purple solid (allow pink)

Allow pink precipitate

1

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

Allow $[Co(NH_3)_5H_2O]^{3+}$

Formula of product

1

Balanced equation

1

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

Allow $[Co(NH_3)_5H_2O]^{3+}$

1

Oxidising agent

1

(e) $[Co(H_2NCH_2CH_2NH_2)_3]^{2+}$

Allow use of en $[Coen_3]^{2+}$

1

Entropy change for reaction is positive

Mark independently

1

Because 4 mol reactants form 7 mol products
(or increase in number of particles)

Or bidentate replaces unidentate

1

(f) $[CoCl_4]^{2-}$

1

Cl^- ligand too big to fit more than 4 round Co^{2+}

Allow Cl^- is bigger
Allow chlorine and Cl but NOT chlorine molecules.

1

[13]

M2. (a) Ti(IV) [Ar]

Or $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

1

Ti(III) $[Ar]3d^1$

Or $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1$

1

Ti(III) has a d electron that can be excited to a higher level

Allow idea that d electrons can be excited to another level (or move between levels)

1

Absorbs one colour of light from white light

Allow idea that light is absorbed

1

Ti(IV) has no d electron so no electron transition with energy equal to that of visible light

Allow Ti(IV) has no d electrons

1

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

1

$[Cr(OH)_6]^{3-}$

1

$[CuCl_4]^{2-}$

1

(c) (i) Rapid determination of concentration

Or easy to get many readings

1

Does not use up any of the reagent/does not interfere with the reaction

Or possible to measure very low concentrations

1

(ii) Curve starts with small gradient (low rate)

1

Because negative ions collide so E_a high

1

Curve gets steeper

1

Because autocatalyst (Mn^{2+}) formed

1

Curve levels out approaching time axis

Can score this mark and next one ONLY with simple curve (that is curve with gradually decreasing gradient)

1

Because MnO_4^- ions used up

5 max

1

[15]

M3. (a) Ligand: -

atom, ion or molecules which can donate a pair of electrons to a metal ion.

1

co-ordinate bond:- a covalent bond

1

in which both electrons are donate by one atom

1

(b) (i) Two correct complex ions

1

Balanced equation

1

Two correct colours

2

(ii) Complex with a bidentate ligand

1

Balanced equation

NB en not allowed as a ligand unless structure also given

1

More molecules/ions formed

1

Increase in entropy

1

more stable complex formed

1

Max 2

(c) Δ*E;* energy absorbed by electron, ground to excited state (QoL)

1

h; Planck's constant or a constant

1

Change in

Oxidation state

1

Ligand

1

Co-ordination number

Apply list principle to incorrect additional answers

1

[16]

M4. (a) Equation:

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

Species

1

Balance

1

Colours:
e.g $[Cu(H_2O)_6]^{2+}$ blue

1

e.g. $[CuCl_4]^{2-}$ yellow/green

1

(b) (i) ΔE: The energy absorbed

1

h: Planck's constant

1

(ii) Factor 1 Change of ligand

1

Factor 2 Change in oxidation state

1

Factor 3 Change in co-ordination number

1

[9]

M1. (a) Electron transitions/electrons excitedin d shell **(1) o**r d-d transition

Do NOT allow charge transfer

(Energy in) visible range **(1)**

(NOT emits in visible region)

2

(b) *Change 1*: (Different) oxidation states **(1)**
Change 2 : (Different) ligands **(1)**
Change 3: (Different) co-ordination number **(1)**

Do not allow shape as an answer

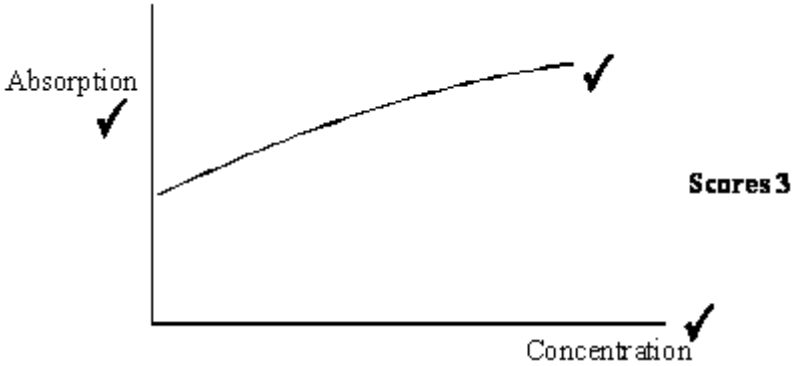
3

(c) Add an appropriate (or a given correct) ligand to <u>intensify colour</u> **(1)**
e.g. thiocyanate $(CNS)^-$ or bipyridyl
Make up solutions of known concentration **(1)**
Measure absorption or transmission **(1)**
Plot graph of results or calibration curve **(1)**
Measure absorption of unknown and **(1)**
compare

N.B.: Allow concentration statement if included in graph statement

Allow adsorption but circle the d

Also



5

[10]

M1.B

[1]

M2.D

[1]

M3.(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]

M4.D

[1]

M5.(a) Co-ordinate / dative / dative covalent / dative co-ordinate

Do not allow covalent alone

1

(b) (lone) pair of electrons on <u>oxygen/O</u>

If co-ordination to O^{2-}, CE=0

1

forms co-ordinate bond with <u>Fe</u> / donates electron pair to <u>Fe</u>

'Pair of electrons on O donated to Fe' scores M1 and M2

1

(c) 180° / 180 / 90

Allow any angle between 85 and 95

Do not allow 120 or any other incorrect angle

Ignore units eg °C

1

(d) (i) 3 : 5 / 5 FeC_2O_4 reacts with 3 MnO_4^-

Can be equation showing correct ratio

1

(ii) **M1** Moles of MnO_4^- per titration = 22.35 × 0.0193/1000 = $\underline{4.31 \times 10^{-4}}$

Method marks for each of the next steps (no arithmetic error allowed for M2):

Allow $\underline{4.3 \times 10^{-4}}$ (2 sig figs)

Allow other ratios as follows:

eg from given ratio of 7/3

1

M2 moles of FeC_2O_4= ratio from (d)(i) used correctly × 4.31×10^{-4}

M2 *= 7/3 × 4.31×10^{-4} = 1.006×10^{-3}*

1

M3 moles of FeC_2O_4 in 250 cm^3 = M2 ans × 10

M3 *= $1.006 \times 10^{-3} \times 10 = 1.006 \times 10^{-2}$*

1

M4 Mass of $FeC_2O_4.2H_2O$ = M3 ans × 179.8

M4 *= $1.006 \times 10^{-2} \times 179.8 = 1.81$ g*

1

M5 % of $FeC_2O_4.2H_2O$ = (M4 ans/1.381) × 100

M5 *= 1.81 × 100/1.381 = 131 % (130 to 132)*

1

(OR for M4 max moles of $FeC_2O_4.2H_2O$ = 1.381/179.8 (= 7.68×10^{-3})
for M5 % of $FeC_2O_4.2H_2O$ = (M3 ans/above M4ans) × 100)
eg using correct ratio 5/3:
Moles of FeC_2O_4 = 5/3 × 4.31×10^{-4} = 7.19×10^{-4}
Moles of FeC_2O_4 in 250 cm^3 = $7.19 \times 10^{-4} \times 10 = 7.19 \times 10^{-3}$
Mass of $FeC_2O_4.2H_2O$ = $7.19 \times 10^{-3} \times 179.8 = 1.29$ g
% of $FeC_2O_4.2H_2O$ = 1.29 × 100/1.381 = 93.4 (allow 92.4 to 94.4)
Note correct answer (92.4 to 94.4) scores 5 marks

Allow consequentially on candidate's ratio
eg ***M2*** *= 5/2 × 4.31 × 10^{-4} = 1.078 × 10^{-3}*
M3 *= 1.0078 × 10^{-3} × 10 = 1.078 × 10^{-2}*
M4 *= 1.078 × 10^{-2} × 179.8 = 1.94 g*
M5 *= 1.94 × 100/1.381 = 140 % (139 to 141)*
Other ratios give the following final % values
1:1 gives 56.1% (55.6 to 56.6)
5:1 gives 281% (278 to 284)
5:4 gives 70.2% (69.2 to 71.2)

[10]

M6. (a) Same phase/state

1

(b) Because only exist in one oxidation state

Allow do not have variable oxidation states

1

(c) $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$

Ignore state symbols
Allow multiples

1

(d) Both (ions)have a negative charge

Or both have the same charge
Or (ions) repel each other
Do not allow both molecules have the same charge (contradiction)

1

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

1

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

1

Equations can be in any order

Positive and negative (ions)/oppositely charged (ions)

Mark independently

1

(f) Equations 1 and 2 can occur in any order

Allow idea of Fe^{3+} converted to Fe^{2+} then Fe^{2+} converted back to Fe^{3+}

1

[8]

M7.(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 compounde.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) $[Ca(H_2O)_6]^{2+} + EDTA^{4-} \longrightarrow [CaEDTA]^{2-} + 6H_2O$

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 × 10^{-4} × 1000 / 150 = (2.217 × 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 × 10^{-3} × 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]

M8. (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]

M1. (a) $Pt(NH_3)_2Cl_2 + H_2O \rightarrow [Pt(NH_3)_2Cl(H_2O)]^+ + Cl^-$

Correct product

1

Balanced equation

1

(b) (i) Hydrogen bond

1

Oxygen (or nitrogen)

Only score this mark if type of bond is correct

1

(ii) Co-ordinate

1

Nitrogen (or oxygen)

Bond type must be correct to score this mark but allow M2 if bond is covalent

1

(c) Killing them or causing damage (medical side effects)

Allow any correct side effect (e.g. hair loss)
Allow kills healthy (or normal) cells

1

May attach to DNA in normal cells

1

[8]

M2. (a) A shared <u>electron</u> pair or a <u>covalent</u> bond **(1)**
Both electrons from one atom **(1)**

OR when a Lewis base reacts with a Lewis acid
Mark points separately

2

(b) *Brønsted-Lowry acid*: A proton or H^+ donor **(1)**

Not H_3O^+

Lewis acid: A lone or electron pair acceptor **(1)**

2

(c) Two atoms or two points of attachment **(1)**
Each donating a lone electron pair **(1)**

OR forms 2 (1) co-ordinate bonds (1)
OR donates two (1) pairs of electrons (1)

2

(d) *Change in co-ordination number*: 6 to 4 **(1)**

Reason for change: chloride ligands are larger than water ligands **(1)**

2

OR greater repulsion between chloride ligands
DO NOT allow chlorine or Cl

(e) Same number **(1)**, and same type of bonds **(1)**, broken and made

2

(f) $ClNH_3CH_2CH_2NH_3Cl$ **(1)**

OR $(NH_3CH_2CH_2NH_3)^{2+}$ $2Cl^-$
Allow $C_2H_{10}N_2Cl_2$ and $NH_3ClCH_2CH_2NH_3Cl$

1

[11]

M3. (a) (i) $Fe + 2HCl \rightarrow FeCl_2 + H_2$

(allow ionic formulae)

or $Fe + 2H^+ \rightarrow Fe^{2+} + H_2$

1

(ii) PV = nRT n = PV/RT

(allow either formula but penalise contradiction)

1

$n = \frac{110000 \times 102 \times 10^{-6}}{8.31 \times 298}$

1

= 4.53×10^{-3} (mol)

(answer must have at least 3 sig. figs. Ignore units)

1

(iii) Moles of iron = $4.5(3) \times 10^{-3}$ mol

(allow conseq on (a)(ii))

(or = $4.2(5) \times 10^{-3}$ if candidate uses given moles of hydrogen)

1

Mass of iron = $4.53 \times 10^{-3} \times 55.8 = 0.253$ g
(mark is for method mass = moles × A_r)
(Mass of iron can be 56)

1

(iv) 0.253 × 100/0.263 = 96.1 % (mark is for answer to 2 sig. figs.)

(allow conseq on mass of iron. E.g. = 90% from 4.2(5) × 10^{-3} moles of H_2 and Fe)

(Do not allow answers greater than or equal to 100%)

1

(b) (i) $Fe^{2+} \rightarrow Fe^{3+} + e^-$

(ignore state symbols)

1

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

1

$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$

1

(ii) Moles of dichromate = moles $Fe^{2+}/6$
= $4.53 \times 10^{-3}/6 = 7.55 \times 10^{-4}$

(Allow conseq, mark is for method (a)(iii)/6)

1

Volume of dichromate = moles/concentration
(= $(7.55 \times 10^{-4} \times 1000)/0.0200$)

(mark is for this method)

1

V = 37.75 (cm^3)

(allow 37.7 to 37.8, allow no units but penalise wrong units)

(allow conseq on moles of dichromate)

(if value of 3.63 × 10^{-3} used answer is 30.2 to 30.3, otherwise ans = moles Fe^{2+}/0.00012)

(if mole ratio wrong and candidate does not divide by 6, max score is ONE for volume method)

1

(iii) ($KMnO_4$) will also oxidise (or react with) Cl^- (or chloride or HCl)

1

[14]

M4. (a) Electron transitions/electrons excitedin d shell **(1) o**r d-d transition

Do NOT allow charge transfer

(Energy in) visible range **(1)**

(NOT emits in visible region)

2

(b) *Change 1*: (Different) oxidation states **(1)**
Change 2 : (Different) ligands **(1)**
Change 3: (Different) co-ordination number **(1)**

Do not allow shape as an answer

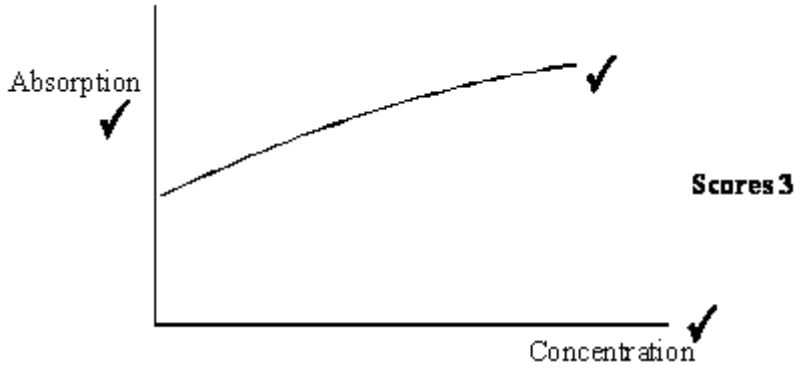
3

(c) Add an appropriate (or a given correct) ligand to <u>intensify colour</u> **(1)**
e.g. thiocyanate $(CNS)^-$ or bipyridyl
Make up solutions of known concentration **(1)**
Measure absorption or transmission **(1)**
Plot graph of results or calibration curve **(1)**
Measure absorption of unknown and **(1)**
compare

N.B.: Allow concentration statement if included in graph statement

Allow adsorption but circle the d

Also



5

[10]

M5. (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]

M6.B

[1]

M1.(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.

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 then stage 3.

Level 3
5 – 6 marks

All stages are covered but the explanation 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 3.

Level 2
3 – 4 marks

Two stages are covered but the explanation 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 but these are not presented in a logical order or show confused reasoning.

Level 1
1 – 2 marks

Insufficient correct chemistry to gain a mark.

Level 0
0 marks

Indicative chemistry content

Stage 1: Electrons round P
- P has 5 electrons in the outside shell
- With 3 electrons from 3 fluorine, there are a total of 8 electrons in outside shell
- so 3 bond pairs, 1 non-bond pair

Stage 2: Electron pair repulsion theory
- Electron pairs repel as far as possible
- Lone pair repels more than bonding pairs

Stage 3: Conclusions
- Therefore, tetrahedral / trigonal pyramidal shape

- With angle of 109(.5)° decreased to 107°

6

(b) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$

Allow correct numbers that are not superscripted

1

(c) Too many electrons in d sub-shell / orbitals

1

(d) Tetrahedral (shape)

1

109.5°

Allow 109°

1

[10]

M2.(a) Percentage of oxygen is 42.5% **(M1)**

Allow if shown clearly in the calculation.

1

Co 13.0 / 58.9 = 0.221, N 18.6 / 14 = 1.329,

K 25.9 / 39.1 = 0.662, O 42.5 / 16 = 2.656 **(M2)**

Allow alternative method if chemically correct.

*If A_r has been divided by the percentage, chemical error, lose **M2** and **M3**.*

1

$CoN_6K_3O_{12}$ **(M3)**

Allow in any order.

Correct answer without working scores this mark only.

1

(b) $Co(NO_2)_6^{3-}$

Allow a correct diagram bonding through N or O

Do not allow $CoN_6O_{12}^{3-}$

Must have correct overall charge.

Allow consequential answer from part(a) if the charge on the anion is correct.

1

[4]

M3. (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]

M4.(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 compounde.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) $[Ca(H_2O)_6]^{2+} + EDTA^{4-} \longrightarrow [CaEDTA]^{2-} + 6H_2O$

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]

M5.(a) A ligand is an electron pair / lone pair donor

Allow uses lone / electron pair to form a co-ordinate bond

1

A bidentate ligand donates two electron pairs (to a transition metal ion) from different atoms / two atoms (on the same molecule / ion)

QoL

1

(b) $CoCl_4^{2-}$ diagram

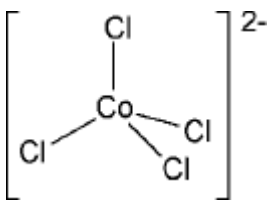
1

Tetrahedral shape

1

109°28’

1



Four chlorines attached to Co with net 2− charge correct

Charge can be placed anywhere, eg on separate formula

Penalise excess charges

Allow 109° to 109.5°

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

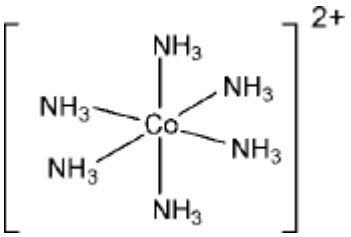
1

Octahedral shape

1

90°

1



Six ammonia / NH_3 molecules attached to Co with 2+ charge correct

Allow 180° if shown clearly on diagram

CE= 0 if wrong complex but mark on if only charge is incorrect

(c) In different complexes the d orbitals / d electrons (of the cobalt) will have different energies / d orbital splitting will be different

1

Light / energy is absorbed causing an electron to be excited

1

Different frequency / wavelength / colour of light will be absorbed / transmitted / reflected

1

(d) 1 mol of H_2O_2 oxidises 2 mol of Co^{2+}

Or $H_2O_2 + 2Co^{2+} \rightarrow 2OH^- + 2Co^{3+}$

1

M_r $CoSO_4.7H_2O$ = 281

If M_r wrong, max 3 for M1, M4, M5

1

Moles Co^{2+} = 9.87 / 281 = 0.03512

1

Moles H_2O_2 = 0.03512 / 2 = 0.01756

M4 is method mark for (M3) / 2 (also scores M1)

1

Volume H_2O_2 = (moles × 1000) / concentration
= 0.01756 × 1000) / 5.00

= 3.51 cm^3 / (3.51 × 10^{-3} dm^3)

Units essential for answer

M5 is method mark for (M4) x 1000 / 5
Allow 3.4 to 3.6 cm^3

If no 2:1 ratio or ratio incorrect Max 3 for M2, M3 & M5

Note: Answer of 7 cm^3 scores 3 for M2, M3, M5 (and any other wrong ratio max 3)

Answer of 16.8 cm^3 scores 3 for M1, M4, M5 (and any other wrong M_r max 3)

Answer of 33.5 cm^3 scores 1 for M5 only (so wrong M_r AND wrong ratio max 1)

1

[16]

M1.(a) (i) $EDTA^{4-} + [Cu(H_2O)_6]^{2+} \rightarrow [Cu(EDTA)]^{2-} + 6H_2O$

1

(ii) (Mol EDTA = (6.45/1000) ×0.015 =)9.68×10^{-5} mol Cu(II)

1

Conc. Cu(II) = ((9.68×10^{-5}) / 0.025 =) 0.00387 mol dm^{-3}

Correct answer without working gains M2 only.

1

(b) Samples may not be consistent throughout the river
OR
Concentration may vary over time

Ignore comments on technique.

1

(c) $[Ag(NH_3)_2]^+$

Accept name eg diamminesilver(I) ion.

1

aldehyde

Allow CHO.

1

[6]

M2. (a) Partially filled/incomplete d sub-shell/orbital/shell

Ignore reference to f orbitals
*Do **not** allow d block*
*Do **not** allow half-filled d orbitals*

1

(b) Has ligand(s)

Allow molecules/ions with lone pairs

1

linked by co-ordinate bonds

Allow dative/donation of lone pair

1

(c) (Blue) light is absorbed (from incident white light)

1

Due to electrons moving to higher levels/electrons excited

Allow d → d transitions

1

Red light (that) remains (is transmitted)/light that remains (transmitted light) is the colour observed

Allow red light reflected

1

(d) (i) Circle round any O^-

List principle

1

Circle round either N

1

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

Allow missing square brackets
Ignore state symbols

1

(iii) Increase in entropy/Δ*S* positive

Or increase in disorder

1

Because 2 mol (of particles/molecules/species/entities) form 7 mol

Allow 'increase in number' as stated in words or as shown by any numbers deduced correctly from an incorrect equation

Do not allow increase in ions/atoms

1

(e) (i) Co-ordinate/dative/dative covalent bond

Allow pair of electrons donated by nitrogen/ligand

Do not allow pair of electrons donated from Iron/Fe

1

Covalent bond

Shared electron pair

1

(ii) Transport of oxygen/O_2

Allow any statement that implies oxygen carried (around the body)

Do not allow transport of carbon dioxide (CO_2). This also contradicts the mark (list principle)

1

(iii) Because it bonds to the iron/haemoglobin

Allow blocks site
/CO has greater affinity for haemoglobin
/carboxyhaemoglobin more stable than oxyhaemoglobin

1

Displaces <u>oxygen</u>

Or prevents transport of <u>oxygen</u>
QoL

1

[16]

M3. Linear complex e.g. $[Ag(NH_3)_2]^+$ **(1)**

Tetrahedral complex e.g. $[CoCl_4]^{2-}$ **(1)**

Octahedral complex e.g. $[Fe(H_2NCH_2CH_2NH_2)_3]^{3+}$

*Species **(1)***
*Charge **(1)***

[4]

M4. (a) $[Co(H_2O)_6]^{2+}$

1

octahedral

Only allow if species has 6 ligands
but allow if M1 not given because charge missing

1

(b) $CoCO_3$

Mark independently

1

Purple solid (allow pink)

Allow pink precipitate

1

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

Allow $[Co(NH_3)_5H_2O]^{3+}$

Formula of product

1

Balanced equation

1

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

Allow $[Co(NH_3)_5H_2O]^{3+}$

1

Oxidising agent

1

(e) $[Co(H_2NCH_2CH_2NH_2)_3]^{2+}$

Allow use of en $[Coen_3]^{2+}$

1

Entropy change for reaction is positive

Mark independently

1

Because 4 mol reactants form 7 mol products
(or increase in number of particles)

Or bidentate replaces unidentate

1

(f) $[CoCl_4]^{2-}$

1

Cl^- ligand too big to fit more than 4 round Co^{2+}

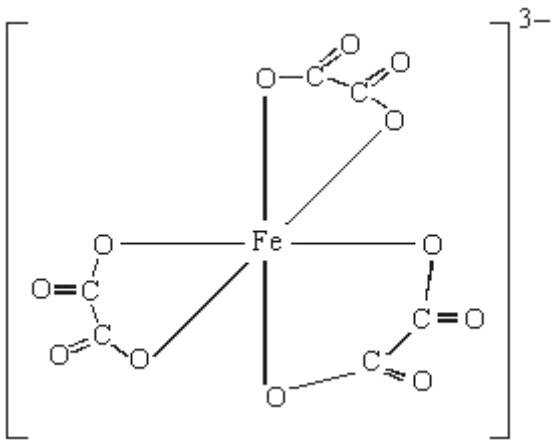
Allow Cl^- is bigger
Allow chlorine and Cl but NOT chlorine molecules.

1

[13]

M1. (a) (i) Two **(1)** lone pair donor / electron pair donor **(1)** atoms
Allow:– forms two co-ordinate bonds **(1)**
NOT atom with two lone pairs

(ii)



(O
C not essential)

*Correct ligand structure **(1)***
penalise any error
*Six correct O–Fe bonds **(1)***
*Correct charge **(1)***
N.B. Penalise the second mark if arrow from Fe shown
N.B. Ignore charges on atoms

5

(b) (Substitution of a monodentate ligand by a) bi or multidentate ligand **(1)** giving a more stable complex **(1)** or with an increase in entropy / disorder or forming a ring / cage complex / structure (crab like)

2

(c) (i) $[AgCl_2]^-$ or $AgCl_2^-$ **(1)**

(ii) Chloride or Cl^- big or large or repel **(1)**
NOT Cl_2 or Cl^+ or Cl

Allow 'chlorine ion'

2

(d) (i) (Both) ions are negative or ions repel or High E_a **(1)**

(ii) *Meaning of the term autocatalytic:* A product of the reaction acts as a catalyst **(1)**

NOT a self catalysing reaction (0)

Catalyst: Mn^{2+} or Mn^{3+} **(1)**

(iii) Mn^{2+} converted into Mn^{n+} or Mn^{2+} oxidised **(1)**
Mn^{n+}/oxidised species then <u>oxidises/reacts with $C_2O_4^{2-}$</u> **(1)**

5

[14]

M2. D

[1]

M3. (a) $C_2O_4^{2-}$ or $H_2NCH_2CH_2NH_2$ **(1)**

1

(b) $[AgCl_2]^-$ or $[Ag(CN)_2]^-$ or $[Ag(NH_3)_2]^+$ **(1)**

1

(c) e.g. $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$
Correct complex species **(1),** Balanced **(1),** Only allow if species correct

2

(d) e.g. $[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$
Correct complex species **(1),** Balanced **(1),** Only allow if species correct

2

(e) *Equation:* $[Co(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Co(EDTA)]^{2-} + 6H_2O$ **(1)**
Explanation: More molecules on right hand side **(1)**
Entropy increases **(1)**

3

[9]

M4. (a) A shared electron pair or a covalent bond **(1)**
Both electrons from one atom **(1)**

OR when a Lewis base reacts with a Lewis acid
Mark points separately

2

(b) *Brønsted-Lowry acid*: A proton or H^+ donor **(1)**

Not H_3O^+

Lewis acid: A lone or electron pair acceptor **(1)**

2

(c) Two atoms or two points of attachment **(1)**
Each donating a lone electron pair **(1)**

OR forms 2 (1) co-ordinate bonds (1)
OR donates two (1) pairs of electrons (1)

2

(d) *Change in co-ordination number*: 6 to 4 **(1)**

Reason for change: chloride ligands are larger than water ligands **(1)**

2

OR greater repulsion between chloride ligands
DO NOT allow chlorine or Cl

(e) Same number **(1)**, and same type of bonds **(1)**, broken and made

2

(f) $ClNH_3CH_2CH_2NH_3Cl$ **(1)**

OR $(NH_3CH_2CH_2NH_3)^{2+}$ $2Cl^-$
Allow $C_2H_{10}N_2Cl_2$ *and* $NH_3ClCH_2CH_2NH_3Cl$

1

[11]

M1.(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]

M2.(a) Cobalt has variable oxidation states

Allow exists as Co(II) and Co(III)

1

(It can act as an intermediate that) lowers the activation energy

Allow (alternative route with) lower E_a

1

$CH_3CHO + 2Co^{3+} + H_2O \rightarrow CH_3COOH + 2Co^{2+} + 2H^+$

Allow multiples; allow molecular formulae

Allow equations with H_3O+

1

$\frac{1}{2} O_2 + 2Co^{2+} + 2H^+ \rightarrow 2Co^{3+} + H_2O$

1

(b) (i) $[Co(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$

Do not allow en in equation, allow $C_2H_8N_2$

1

The number of particles increases / changes from 4 to 7

Can score M2 and M3 even if equation incorrect or missing provided number of particles increases

1

So the entropy change is positive / disorder increases / entropy increases

1

(ii) Minimum for **M1** is 3 bidentate ligands bonded to Co

Ignore all charges for M1 and M3 but penalise charges on any ligand in M2

1

Ligands need not have any atoms shown but diagram must show 6 bonds from ligands to Co, 2 from each ligand

Minimum for **M2** is one ligand identified as H_2N-----NH_2

Allow linkage as −C−C− or just a line.

1

Minimum for **M3** is one bidentate ligand showing two arrows from separate nitrogens to cobalt

1

(c) Moles of cobalt = (50 × 0.203) / 1000 = <u>0.01015</u> mol

Allow 0.0101 to 0.0102

1

Moles of AgCl = 4.22/143.4 = 0.0294

Allow 0.029

*If not AgCl (eg $AgCl_2$ or $AgNO_3$), lose this mark and can only score **M1, M4** and **M5***

1

Ratio = Cl^- to Co = 2.9 : 1

*Do not allow 3 : 1 if this is the only answer but if 2.9:1 seen somewhere in answer credit this as **M3***

1

$[Co(NH_3)_6]Cl_3$ (square brackets not essential)

1

Difference due to incomplete oxidation in the preparation

Allow incomplete reaction.

Allow formation $[Co(NH_3)_5Cl]Cl_2$ etc.

Some chloride ions act as ligands / replace NH_3 in complex.

Do not allow 'impure sample' or reference to practical deficiencies

1

[15]

M3.(a) Water in the gaseous state from the precipitate absorbed by drying agent

OR

Water vapour from the precipitate absorbed by drying agent

Allow 'water vapour reacts with drying agent'.

Do not allow 'absorb water' without qualification.

1

(b) (Blue to) pink / pink colour observed

1

[2]

M4.(a) Electron pair donor

Allow lone pair 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) blue precipitate/solid

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 + $4H^+ \longrightarrow 2H_2O$

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]

M5.(a) (i) Two rings only around nitrogen or sulfur

Lose this mark if more than 2 atoms are ringed.

Do not allow two atoms at the same end of the ion.

1

(ii) 275.8

Accept this answer only. Do not allow 276

1

(iii) Carboxylate / COO^-

Allow salt of carboxylic acid or just carboxylic acid.

1

(b) (32.1 / 102.1) = 31.4%

Do not penalise precision but do not allow 1 significant figure.

1

(c) Zineb is mixed with a solvent / water

Max=2 if M1 missed

1

Use of column / paper / TLC

Lose M1 and M2 for GLC

1

Appropriate collection of the ETU fraction
OR Appropriate method of detecting ETU

Allow ETU is an early fraction in a column or collecting a range of samples over time, lowest retention time / travels furthest on paper or TLC (allow 1 mark for having the longest retention time in GLC).

1

Method of identification of ETU (by comparison with standard using chromatography)

If method completely inappropriate, only M1 is accessible

1

[8]

M1.(a) (i) absorbs (certain frequencies of) (white) light / photons

not absorbs white / u.v. light

1

d electrons excited / promoted

or d electrons move between levels / orbitals

d electrons can be implied elsewhere in answer

1

the colour observed is the light not absorbed / light reflected / light transmitted

allow blue light transmitted

penalise emission of light in M3

1

(ii) ΔE is the energy gained by the (excited) electrons (of Cu^{2+})

allow:

- *energy difference between orbitals / sub-shells*
- *energy of photon / light absorbed*
- *change in energy of the electrons energy lost by excited electrons*
- *energy of photon / light emitted*

1

h (Planck's) constant

1

v frequency of light (absorbed by $Cu^{2+}(aq)$)

do not allow wavelength

If energy lost / photon lost / light emitted in M1 do not penalised light emitted

1

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

note that $[CuCl_4^-]^{2-}$ is incorrect

penalise charges shown separately on the ligand and overall

penalise HCl

1

tetrahedral

1

Cl^- / Cl / chlorine too big (to fit more than 4 round Cu)

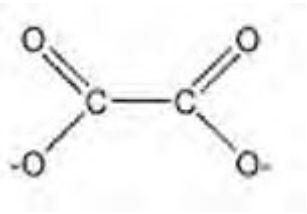
allow

water smaller than Cl^-

explanation that change in shape is due to change in <u>co-ordination number</u>

1

(b)



allow:

- *ion drawn with any bond angles*
- *ion in square brackets with overall / 2- charge shown outside the brackets*
- *ion with delocalised O=C–O bonds in carboxylate group(s)*

1

<u>lone pair</u>(s) on O^- / O

allow position of lone pair(s) shown on O in the diagram even if the diagram is incorrect.

1

(c) (i) $[Cu(H_2O)_6]^{2+} + 2C_2O_4^{2-} \rightarrow [Cu(C_2O_4)_2(H_2O)_2]^{2-} + 4H_2O$

product correct

1

equation balanced

1

6

note can only score M3 and M4 if M1 awarded or if complex in equation has 2 waters and 2 ethanedioates

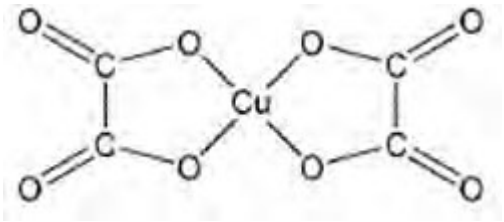
1

octahedral

If this condition is satisfied the complex can have the wrong charge(s) to allow access to M3 and M4 but not M1

1

(ii)



ignore charges

diagram must show both ethanedioates with correct bonding

ignore water

1

90°

allow 180°

mark bond angle independently but penalise if angle incorrectly labelled / indicated on diagram

1

[17]

M2.(a) (ligand) substitution

Allow 'ligand exchange'.

1

(b) To displace <u>the equilibrium</u> to the right

To ensure reaction goes to completion.

1

To improve the yield

Allow 'to replace all chlorines'.

1

(c) (i) $K_2PtCl_4 + 4KI \rightarrow K_2PtI_4 + 4KCl$

Allow correct ionic equations $PtCl_4^{2-} + 4I^- \rightarrow PtI_4^{2-} + 4Cl^-$

Allow multiples and fractions.

1

(ii) = (780.9) ×100 / (415.3 + 664)

Working must be clearly shown.

Allow one mark for correct relationship even if M_r values are incorrect eg using values from ionic equation.

1

= 72.4

Allow 72%

1

(d) (i) $Ag^+ + I^- \rightarrow AgI$

Ignore state symbols even if incorrect.

This equation only.

1

(ii) Stops the reverse reaction / equilibrium displaced to the right

1

(e) Number of steps in the process

Allow 'equilibrium may lie on the reactant side' / side reactions / isomer formation.

1

Losses at each stage of the synthesis

Equilibrium losses or practical losses or yield not 100% for each step.

1

(f) Minimum amount of hot solvent

Accept 'small' for minimum.

Accept water.

1

Cool / crystallise

1

Filter

1

(g) (i) Small amounts are more likely to kill cancer cells rather than the patient

1

(ii) Wear gloves / wash hands after use

Ignore masks.

Apply the list principle if more than one answer.

1

[15]

M3.(a) (i) $EDTA^{4-} + [Cu(H_2O)_6]^{2+} \rightarrow [Cu(EDTA)]^{2-} + 6H_2O$

1

(ii) (Mol EDTA = (6.45/1000) ×0.015 =)9.68×10^{-5} mol Cu(II)

1

Conc. Cu(II) = ((9.68×10^{-5}) / 0.025 =) 0.00387 mol dm^{-3}

Correct answer without working gains M2 only.

1

(b) Samples may not be consistent throughout the river

OR

Concentration may vary over time

Ignore comments on technique.

1

(c) $[Ag(NH_3)_2]^+$

Accept name eg diamminesilver(I) ion.

1

aldehyde

Allow CHO.

1

[6]

M1. (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]

M2. C

[1]

M3. (a) (i) Ammonia

If reagent is missing or incorrect cannot score M3

1

Starts as a pink (solution)

1

Changes to a yellow/straw (solution)

Allow pale brown

Do not allow reference to a precipitate

1

(ii) (dark) brown

Do not allow pale/straw/yellow-brown (i.e. these and other shades except for dark brown)

1

(b) (i) Ruby/red-blue/purple/violet/green

Do not allow red or blue

If ppt mentioned contradiction/CE =0

1

Green

If ppt mentioned contradiction/CE =0

1

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

1

Formula of product

Can score this mark in (b) (ii)

1

(ii) $H_2O_2 + 2e^- \rightarrow 2OH^-$

1

$2[Cr(OH)_6]^{3-} + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O + 2OH^-$

Allow 1 mark out of 2 for a balanced half-equation such as $Cr(III) \rightarrow Cr(VI) + 3e^-$

or $Cr^{3+} + 4H_2O \rightarrow CrO_4^{2-} + 8H^+ + 3e^-$ *etc*

also for $2Cr(III) + 3H_2O_2 \rightarrow 2CrO_4^{2-}$ *(unbalanced)*

2

Yellow

Do not allow orange

1

(c) $2MnO_4^- + 6H^+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$

if no equation and uses given ratio can score M2, M3, M4 & M5

1

Moles MnO_4^- = (24.35/1000) × 0.0187 = $\underline{4.55 \times 10^{-4}}$

Note value must be quoted to at least 3 sig. figs.

M2 is for 4.55×10^{-4}

1

Moles H_2O_2 = (4.55×10^{-4}) $\underline{\times 5/2}$ = 1.138×10^{-3}

M3 is for × 5/2 (or 7/3)

Mark consequential on molar ratio from candidate's equation

1

Moles H_2O_2 in 5 cm^3 original

M4 is for × 10

1

= (1.138×10^{-3}) $\underline{\times 10}$ = 0.01138

Original $[H_2O_2]$ = 0.01138 $\underline{\times (1000/5)}$ = 2.28 mol dm^{-3}

(allow 2.25-2.30)

M5 is for consequentially correct answer from (answer to mark 4) × (1000/5)

Note an answer of between 2.25 and 2.30 is worth 4 marks)

If candidate uses given ratio 3/7 max 4 marks:
***M1**: Moles of MnO_4^- = $\underline{4.55 \times 10^{-4}}$*
***M2**: Moles H_2O_2 = $(4.55 \times 10^{-4}) \underline{\times 7/3} = 1.0617 \times 10^{-3}$*
***M3**: Moles H_2O_2 in 5 cm^3 original*
= $(1.0617 \times 10^{-3}) \times 10 = 0.01062$
M4: Original $[H_2O_2] = 0.01062 \times (1000/5) = 2.12$ mol dm^{-3}
(allow 2.10 to 2.15)

1

[17]

M4.(a) $3C_2O_4^{2-} + [Co(H_2O)_6]^{2+} \rightarrow [Co(C_2O_4)_3]^{4-} + 6H_2O$

Accept multiples.
Equation must have cobalt(II) hexaaqua ion.

1

(b) Ethanedioate ion reduces iron(III) ion **or**
iron(III) ion oxidises ethanedioate ion

Allow answer using equations.

1

$E^{\ominus}(CO_2 / C_2O_4^{2-})$ more negative than $E^{\ominus}$ (Fe^{3+} / Fe^{2+}) **or**
$E^{\ominus}$ $(Fe^{3+} / Fe^{2+}) > E^{\ominus}$ $(CO_2 / C_2O_4^{2-})$
or e.m.f. positive **or** cell voltage = +1.26

1

[3]

M5. (a) W is $CuCl_4^{2-}$

1

Yellow-green/yellow/green

Not necessary to indicate solution
Do not allow precipitate/solid

1

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

Allow + $4HCl \rightarrow 4H^+$

1

(b) X is $Cu(H_2O)_4(OH)_2$

Allow $Cu(OH)_2$/copper hydroxide

1

Blue precipitate/solid

Ignore shades

1

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

Allow any balanced equation/equations leading to this hydroxide or $Cu(OH)_2$
But must use ammonia

1

(c) Y is $[Cu(NH_3)_4(H_2O)_2]^{2+}$

1

Deep/dark/royal <u>blue solution</u>

QoL

1

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

Accept equation for formation from $Cu(OH)_2$

1

(d) Z is $CuCO_3$

Allow copper carbonate

1

Green solid/precipitate

Allow blue-green precipitate

1

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

1

(e) (i) $Cu^{2+}(aq) + Fe(s) \rightarrow Cu(s) + Fe^{2+}(aq)$

Allow hydrated ions
State symbols not essential but penalise if wrong

1

Blue

Do not allow description of solids

1

Green

Allow yellow/(red-)brown/orange

1

(ii) Any two correct points about copper extraction from two of these three categories:

Any relevant mention of lower energy consumption

Do not allow reference to electricity alone or to temperature alone.

Any relevant mention of benefits of less mining (of copper ore)

Allow avoids depletion of (copper ore) resources

Less release of CO_2 (or CO) into the atmosphere

Not just greenhouse gases. Must mention CO_2 or CO

Max 2

[17]

M1. (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]

M2. (a) Ligand: -
atom, ion or molecules which can donate a pair of electrons to a metal ion.

1

co-ordinate bond:- a covalent bond

1

in which both electrons are donate by one atom

1

(b) (i) Two correct complex ions

1

Balanced equation

1

Two correct colours

2

(ii) Complex with a bidentate ligand

1

Balanced equation

NB en not allowed as a ligand unless structure also given

1

More molecules/ions formed

1

Increase in entropy

1

more stable complex formed

1

Max 2

(c) Δ*E;* energy absorbed by electron, ground to excited state (QoL)

1

h; Planck's constant or a constant

1

Change in

Oxidation state

1

Ligand

1

Co-ordination number

Apply list principle to incorrect additional answers

1

[16]

M3. (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]

M4. (a) $C_2O_4^{2-}$ or $H_2NCH_2CH_2NH_2$ **(1)**

1

(b) $[AgCl_2]^-$ or $[Ag(CN)_2]^-$ or $[Ag(NH_3)_2]^+$ **(1)**

1

(c) e.g. $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$
Correct complex species **(1),** Balanced **(1),** Only allow if species correct

2

(d) e.g. $[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$
Correct complex species **(1),** Balanced **(1),** Only allow if species correct

2

(e) *Equation:* $[Co(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Co(EDTA)]^{2-} + 6H_2O$ **(1)**
Explanation: More molecules on right hand side **(1)**
Entropy increases **(1)**

3

[9]

M1. (a) A shared <u>electron</u> pair or a <u>covalent</u> bond **(1)**
Both electrons from one atom **(1)**

OR when a Lewis base reacts with a Lewis acid
Mark points separately

2

(b) *Brønsted-Lowry acid*: A proton or H^+ donor **(1)**

Not H_3O^+

Lewis acid: A lone or electron pair acceptor **(1)**

2

(c) Two atoms or two points of attachment **(1)**
Each donating a lone electron pair **(1)**

OR forms 2 (1) co-ordinate bonds (1)
OR donates two (1) pairs of electrons (1)

2

(d) *Change in co-ordination number*: 6 to 4 **(1)**

Reason for change: chloride ligands are larger than water ligands **(1)**

2

OR greater repulsion between chloride ligands
DO NOT allow chlorine or Cl

(e) Same number **(1)**, and same type of bonds **(1)**, broken and made

2

(f) $ClNH_3CH_2CH_2NH_3Cl$ **(1)**

OR $(NH_3CH_2CH_2NH_3)^{2+}$ $2Cl^-$
Allow $C_2H_{10}N_2Cl_2$ and $NH_3ClCH_2CH_2NH_3Cl$

1

[11]

M2.D

[1]

M3.A

[1]

M1.C

[1]

M2.C

[1]

M3.A

[1]

M4.D

[1]

M5.D

[1]

M6.B

[1]

M7.D

[1]

M8.A

[1]

M9.C

[1]

M10.D

[1]

M11.D

[1]

M12.B

[1]

M13.C

[1]

M14.C

[1]

M15.D

[1]

M16.D

[1]

M17.A

[1]

M18.A

[1]

M19.D

[1]

M20.D

[1]

M21.B

[1]

M1.(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]

M2.(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]

M3.(a) Cobalt has variable oxidation states

Allow exists as Co(II) and Co(III)

1

(It can act as an intermediate that) lowers the activation energy

Allow (alternative route with) lower E_a

1

$CH_3CHO + 2Co^{3+} + H_2O \rightarrow CH_3COOH + 2Co^{2+} + 2H^+$

Allow multiples; allow molecular formulae

Allow equations with H_3O^+

1

$\frac{1}{2} O_2 + 2Co^{2+} + 2H^+ \rightarrow 2Co^{3+} + H_2O$

1

(b) (i) $[Co(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$

Do not allow en in equation, allow $C_2H_8N_2$

1

The number of particles increases / changes from 4 to 7

Can score M2 and M3 even if equation incorrect or missing provided number of particles increases

1

So the entropy change is positive / disorder increases / entropy increases

1

(ii) Minimum for **M1** is 3 bidentate ligands bonded to Co

Ignore all charges for M1 and M3 but penalise charges on any ligand in M2

1

Ligands need not have any atoms shown but diagram must show 6 bonds from ligands to Co, 2 from each ligand

Minimum for **M2** is one ligand identified as H_2N-----NH_2

Allow linkage as −C−C− or just a line.

1

Minimum for **M3** is one bidentate ligand showing two arrows from separate nitrogens to cobalt

1

(c) Moles of cobalt = (50 × 0.203) / 1000 = 0.01015 mol

Allow 0.0101 to 0.0102

1

Moles of AgCl = 4.22/143.4 = 0.0294

Allow 0.029

*If not AgCl (eg $AgCl_2$ or $AgNO_3$), lose this mark and can only score **M1, M4** and **M5***

1

Ratio = Cl^- to Co = 2.9 : 1

*Do not allow 3 : 1 if this is the only answer but if 2.9:1 seen somewhere in answer credit this as **M3***

1

$[Co(NH_3)_6]Cl_3$ (square brackets not essential)

1

Difference due to incomplete oxidation in the preparation

Allow incomplete reaction.

Allow formation $[Co(NH_3)_5Cl]Cl_2$ etc.

Some chloride ions act as ligands / replace NH_3 in complex.

Do not allow 'impure sample' or reference to practical deficiencies

1

[15]

M4.(a) **Y**

1

(b) **X**

1

(c) Jump in trend of ionisation energies after removal of fifth electron

Fits with an element with 5 outer electrons ($4s^2 3d^3$) like V

1

(d) Explanation: Two different colours of solution are observed

1

Because each colour is due to vanadium in a different oxidation state

1

(e) **Stage 1:** mole calculations in either order

Moles of vanadium = $50.0 \times 0.800 / 1000 = 4.00 \times 10^{-2}$

Extended response

Maximum of 5 marks for answers which do not show a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.

1

Moles of SO_2 = pV / RT = $(98\,000 \times 506 \times 10^{-6}) / (8.31 \times 293)$

$= 2.04 \times 10^{-2}$

1

Stage 2: moles of electrons added to NH_4VO_3

When SO_2 (sulfur(IV) oxide) acts as a reducing agent, it is oxidised to sulfate(VI) ions so this is a two electron change

1

Moles of electrons released when SO_2 is oxidised = $2.04 \times 10^{-2} \times 2$

$= 4.08 \times 10^{-2}$

1

Stage 3: conclusion

But in NH_4VO_3 vanadium is in oxidation state 5

1

4.00×10^{-2} mol vanadium has gained 4.08×10^{-2} mol of electrons
therefore 1 mol vanadium has gained $4.08 \times 10^{-2} / 4.00 \times 10 - 2 = 1$ mol of electrons to the nearest integer, so new oxidation state is 5 – 1 = 4

1

[11]

M5.(a) Negative ions repel one another

1

(b) Positive ions attract 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]

M6.(a) moles of $Cr_2O_7^{2-}$ per titration = 21.3 × 0.0150 / 1000 = $\underline{3.195 \times 10^{-4}}$

1

($Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$) $Cr_2O_7^{2-}$:Fe^{2+} = 1:6

If 1:6 ratio incorrect cannot score M2 or M3

1

moles of $Fe^{2+} = 6 \times 3.195 \times 10^{-4} = 1.917 \times 10^{-3}$

Process mark for M1 × 6 (also score M2)

1

original moles in 250 $cm^3 = 1.917 \times 10^{-3} \times 10 = 1.917 \times 10^{-2}$

Process mark for M3 × 10

1

mass of $FeSO_4.7H_2O = 1.917 \times 10^{-2} \times 277.9 = 5.33$ (g)

Mark for answer to M4 × 277.9

(allow 5.30 to 5.40)

*Answer **must** be to at least 3 sig figs*

Note that an answer of 0.888 scores M1, M4 and M5 (ratio 1:1 used)

1

(b) (Impurity is a) reducing agent / reacts with dichromate / impurity is a version of $FeSO_4$ with fewer than 7 waters (not fully hydrated)

Allow a reducing agent or compound that that converts Fe^{3+} into Fe^{2+}

1

Such that for a given mass, the impurity would react with more dichromate than a similar mass of $FeSO_4.7H_2O$

OR for equal masses of the impurity and $FeSO_4.7H_2O$, the impurity would react with more dichromate.

Must compare mass of impurity with mass of $FeSO_4.7H_2O$

1

[7]

M1.(a) $FeSO_4 + Na_2C_2O_4 \rightarrow FeC_2O_4 + Na_2SO_4$

Allow multiples, including fractions.

Allow $Fe^{2+} + C_2O_4^{2-} \rightarrow FeC_2O_4$

Allow correct equation which includes water of crystallisation.

1

(b) M_r $FeSO_4.7H_2O$ = 277.9

Allow if shown clearly in the calculation.

Allow 278

1

Moles = 6.95 / 277.9 = 2.5(0) × 10^{-2}

Do not penalise precision but must be to a minimum of two significant figures.

Allow correct calculation using incorrect M_r.

Correct answer without working scores this mark only.

1

(c) 3(.00) × 10^{-2}

1

(d) Theoretical mass = 2.50 × 10^{-2} × 179.8 = 4.50g
as long as 2.50 × 10^{-2} is the smaller of parts (b) and (c) **(M1)**

Allow consequential answer from parts (b) and (c).

Allow theoretical mass = (smaller of parts (b) and (c)) × 179.8

*If larger of parts (b) and (c) used, lose **M1** but can score **M2**.*

Allow answers based on moles of reactant and product.

1

Yield = 3.31 × 100 / 4.50 = 73.6% **(M2)**

Award this mark only if answer given to 3 significant figures.

Correct answer without working scores this mark only, provided answer given to 3 significant figures.

1

(e) Some left in solution / some lost during filtration

Do not allow 'incomplete reaction'.

Do not allow 'reaction is reversible'.

1

(f) MnO_4^- will oxidise the iron(II) ion and the ethanedioate ion

1

MnO_4^- does not oxidise the Cu^{2+} ion / larger volume needed for iron(II) ethanedioate

1

[9]

M2.(a) A ligand is an electron pair / lone pair donor

Allow uses lone / electron pair to form a co-ordinate bond

1

A bidentate ligand donates two electron pairs (to a transition metal ion) from different atoms / two atoms (on the same molecule / ion)

QoL

1

(b) $CoCl_4^{2-}$ diagram

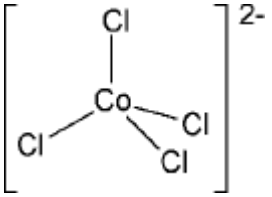
1

Tetrahedral shape

1

109°28'

1



Four chlorines attached to Co with net 2− charge correct

Charge can be placed anywhere, eg on separate formula

Penalise excess charges

Allow 109° to 109.5°

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

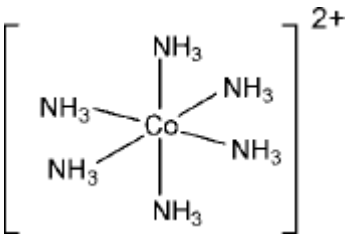
1

Octahedral shape

1

90°

1



Six ammonia / NH_3 molecules attached to Co with 2+ charge correct

Allow 180° if shown clearly on diagram

CE= 0 if wrong complex but mark on if only charge is incorrect

(c) In different complexes the d orbitals / d electrons (of the cobalt) will have different energies / d orbital splitting will be different

1

Light / energy is absorbed causing an electron to be excited

1

Different frequency / wavelength / colour of light will be absorbed / transmitted / reflected

1

(d) 1 mol of H_2O_2 oxidises 2 mol of Co^{2+}

Or $H_2O_2 + 2Co^{2+} \rightarrow 2OH^- + 2Co^{3+}$

1

M_r $CoSO_4.7H_2O$ = 281

If M_r wrong, max 3 for M1, M4, M5

1

Moles Co^{2+} = 9.87 / 281 = 0.03512

1

Moles H_2O_2 = 0.03512 / 2 = 0.01756

M4 is method mark for (M3) / 2 (also scores M1)

1

Volume H_2O_2 = (moles × 1000) / concentration
= 0.01756 × 1000) / 5.00

= 3.51 cm^3 / (3.51 × 10^{-3} dm^3)

Units essential for answer

M5 is method mark for (M4) x 1000 / 5
Allow 3.4 to 3.6 cm^3

If no 2:1 ratio or ratio incorrect Max 3 for M2, M3 & M5

Note: Answer of 7 cm^3 scores 3 for M2, M3, M5 (and any other wrong ratio max 3)

Answer of 16.8 cm^3 scores 3 for M1, M4, M5 (and any other wrong M_r max 3)

Answer of 33.5 cm^3 scores 1 for M5 only (so wrong M_r AND wrong ratio max 1)

1

[16]

M3.(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 <u>different</u> 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 <u>water</u>

Ignore charge/size ratio and mass/charge

1

[19]

M4.(a) Co-ordinate / dative / dative covalent / dative co-ordinate

Do not allow covalent alone

1

(b) (lone) pair of electrons on <u>oxygen/O</u>

If co-ordination to O^{2-}, CE=0

1

forms co-ordinate bond with <u>Fe</u> / donates electron pair to <u>Fe</u>

'Pair of electrons on O donated to Fe' scores M1 and M2

1

(c) 180° / 180 / 90

Allow any angle between 85 and 95

Do not allow 120 or any other incorrect angle

Ignore units eg °C

1

(d) (i) 3 : 5 / 5 FeC_2O_4 reacts with 3 MnO_4^-

Can be equation showing correct ratio

1

(ii) **M1** Moles of MnO_4^- per titration = 22.35 × 0.0193/1000 = <u>4.31×10^{-4}</u>

Method marks for each of the next steps (no arithmetic error allowed for M2):

Allow <u>4.3×10^{-4}</u> (2 sig figs)

Allow other ratios as follows:

eg from given ratio of 7/3

1

M2 moles of FeC_2O_4= ratio from (d)(i) used correctly × 4.31×10^{-4}

M2 *= 7/3 × 4.31×10^{-4} = 1.006×10^{-3}*

1

M3 moles of FeC_2O_4 in 250 cm^3 = M2 ans × 10

M3 *= 1.006 × 10^{-3} × 10 = 1.006 × 10^{-2}*

1

M4 Mass of $FeC_2O_4.2H_2O$ = M3 ans × 179.8

M4 *= 1.006 × 10^{-2} × 179.8 = 1.81 g*

1

M5 % of $FeC_2O_4.2H_2O$ = (M4 ans/1.381) × 100

M5 *= 1.81 × 100/1.381 = 131 % (130 to 132)*

1

(OR for M4 max moles of $FeC_2O_4.2H_2O$ = 1.381/179.8 (= 7.68 × 10^{-3})
for M5 % of $FeC_2O_4.2H_2O$ = (M3 ans/above M4ans) × 100)
eg using correct ratio 5/3:
Moles of FeC_2O_4 = 5/3 × 4.31 × 10^{-4} = 7.19 × 10^{-4}
Moles of FeC_2O_4 in 250 cm^3 = 7.19 × 10^{-4} × 10 = 7.19 × 10^{-3}
Mass of $FeC_2O_4.2H_2O$ = 7.19 × 10^{-3} × 179.8 = 1.29 g
% of $FeC_2O_4.2H_2O$ = 1.29 × 100/1.381 = 93.4 (allow 92.4 to 94.4)
Note correct answer (92.4 to 94.4) scores 5 marks

Allow consequentially on candidate's ratio

*eg **M2** = 5/2 × 4.31 × 10^{-4} = 1.078 × 10^{-3}*

M3 *= 1.0078 × 10^{-3} × 10 = 1.078 × 10^{-2}*

M4 *= 1.078 × 10^{-2} × 179.8 = 1.94 g*

M5 *= 1.94 × 100/1.381 = 140 % (139 to 141)*

Other ratios give the following final % values

1:1 gives 56.1% (55.6 to 56.6)

5:1 gives 281% (278 to 284)

5:4 gives 70.2% (69.2 to 71.2)

[10]

M1.(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]

M2.(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]

M3.(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]

M4.(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]

M5.(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 $H^+ = 25 \times 0.0200 \times 8 / 1000 = 4.00 \times 10^{-3}$

1

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

Allow consequential marking on incorrect moles of H^+

1

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

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

<u>Larger</u> 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]

M6.(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]

M1.(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 compounde.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) $[Ca(H_2O)_6]^{2+} + EDTA^{4-} \longrightarrow [CaEDTA]^{2-} + 6H_2O$

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 × 0.0532 / 1000 = (3.325×10^{-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]

M2. (a) $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$

1

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

1

two negative ions repel / lead to reaction that is slow / lead to reaction that has high E_a

1

iron able to act because changes its oxidation state
allow iron has variable oxidation state

1

With iron ions have alternative route / route with lower activation energy

1

(b) (i) $[Fe(H_2O)_6]^{3+} \rightarrow [Fe(H_2O)_5OH]^{2+} + H^+$
can have H_2O on LHS and H_3O^+ on R
do not penalise further hydrolysis equations
allow high charge density

1

Fe^{3+} ion has higher charge (to size ratio) (than Fe^{2+})

1

increases polarisation of co-ordinated water / attracts O releasing an H^+ ion / weakens O–H bond

1

(ii) $Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$
or 6 mol Fe(II) react with 1 mol dichromate
If factor of 6 not used max = 3 for M2, M4 and M5
e.g. 1:1 gives ans= 8.93 to 8.98% (scores 3)

1

moles dichromate = $23.6 \times 0.218/1000 = 5.14 \times 10^{-4}$

1

moles iron = $5.14 \times 10^{-4} \times 6 = 0.00309$

M3 also scores M1

1

mass iron = $0.00309 \times 55.8 = 0.172$

Mark is for moles of iron × 55.8 conseq

Allow use of 56 for iron

1

% by mass of iron = $0.172 \times 100/0.321 = 53.7\%$

Answer must be to at least 3 sig figures allow 53.6 to 53.9

Mark is for mass of iron × 100/0.321 conseq

1

(c) brown precipitate / solid

Allow red-brown / orange solid

Not red or yellow solid

1

bubbles (of gas) / effervescence/ fizz

Allow gas evolved / given off

Do not allow just gas or CO_2 or CO_2 gas

1

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

Allow

$2[Fe(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2Fe(OH)_3 + 3CO_2 + 9H_2O$

Use of Na_2CO_3

e.g. … + $3Na_2CO_3 \rightarrow$ .. + .. + .. + $6Na^+$

1

[16]

M3. MnO_4^- will oxidise the chloride ion / reaction of MnO_4^- and Cl^- feasible

Accept converse argument with $Cr_2O_7^{2-}$

Accept calculations of overall E° values.

1

Larger volume needed

1

[2]

M4.(a) (i) Propanone evaporates (or similar)

1

Removes water (from the precipitate)

Accept 'removes impurities / excess reagents'.

Accept 'salt insoluble in propanone'.

1

(ii) Add NaOH / NH_3 / Na_2CO_3

1

No green ppt

Accept 'no visible change'.

Must have correct reagent to score this mark.

1

(iii) Some salt dissolves (in propanone) **or** some lost in filtration **or** some Fe^{2+} gets oxidised (to Fe^{3+} in air)

Do not accept 'reaction reversible' or 'incomplete reaction' or similar.

1

(iv) Moles $Fe^{2+} = 2.50 \times 10^{-2}$

Accept 2.5×10^{-2}

1

M_r of salt = 179.8

Allow 180

Allow if 179.8 or 180 appears in a calculation.

1

Mass of salt = $179.8 \times 2.5 \times 10^{-2} \times 0.95 = 4.27$ (g)

Correct answer with no working scores this mark only.

Allow range 4.2 to 4.3 (g)

1

(v) 1.67 mol or correct ratio of $5FeC_2O_4 : 3MnO_4^-$

1

(b) $Ca^{2+} + C_2O_4^{2-} \rightarrow CaC_2O_4$

Accept multiples.

1

(c) (Insoluble) calcium ethanedioate coats surface

Allow 'calcium ethanedioate is insoluble'.

Do not allow answers based on ethanedioic acid being a weak acid.

Do not accept 'acid used up' or 'reaction very fast'.

1

(d) Small amount of tea used **or** concentration of the acid in tea is low

Accept 'high temperature decomposes the acid'.

Accept 'calcium ions in milk form a precipitate with the acid'.

Do not accept 'do not drink tea often' or similar.

1

(e) Mass of acid = 180.0 and mass of reagents = 450.0

Accept 180 and 450.

1

(180 / 450 ×100 =) 40.0%

Do not penalise precision.

Correct answer without working scores this mark only.

1

[14]

M1. (a) (i) $Fe + 2HCl \rightarrow FeCl_2 + H_2$

(allow ionic formulae)

or $Fe + 2H^+ \rightarrow Fe^{2+} + H_2$

1

(ii) $PV = nRT$ $n = PV/RT$

(allow either formula but penalise contradiction)

1

$n = \dfrac{110000 \times 102 \times 10^{-6}}{8.31 \times 298}$

1

$= 4.53 \times 10^{-3}$ (mol)

(answer must have at least 3 sig. figs. Ignore units)

1

(iii) Moles of iron = $4.5(3) \times 10^{-3}$ mol

(allow conseq on (a)(ii))

(or = $4.2(5) \times 10^{-3}$ if candidate uses given moles of hydrogen)

1

Mass of iron = $4.53 \times 10^{-3} \times 55.8 = 0.253$ g
(mark is for method mass = moles × A_r)
(Mass of iron can be 56)

1

(iv) $0.253 \times 100/0.263 = 96.1$ % (mark is for answer to 2 sig. figs.)

(allow conseq on mass of iron. E.g. = 90% from $4.2(5) \times 10^{-3}$ moles of H_2 and Fe)

(Do not allow answers greater than or equal to 100%)

1

(b) (i) $Fe^{2+} \rightarrow Fe^{3+} + e^-$

(ignore state symbols)

1

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

1

$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$

1

(ii) Moles of dichromate = moles $Fe^{2+}/6$

= $4.53 \times 10^{-3}/6 = 7.55 \times 10^{-4}$

(Allow conseq, mark is for method (a)(iii)/6)

1

Volume of dichromate = moles/concentration
(= $(7.55 \times 10^{-4} \times 1000)/0.0200$)

(mark is for this method)

1

V = 37.75 (cm^3)

(allow 37.7 to 37.8, allow no units but penalise wrong units)

(allow conseq on moles of dichromate)

(if value of 3.63×10^{-3} used answer is 30.2 to 30.3, otherwise ans = moles $Fe^{2+}/0.00012$)

(if mole ratio wrong and candidate does not divide by 6, max score is ONE for volume method)

1

(iii) ($KMnO_4$) will also oxidise (or react with) Cl^- (or chloride or HCl)

1

[14]

M2. (a) Ti(IV) [Ar]

Or $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

1

Ti(III) $[Ar]3d^1$

Or $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1$

1

Ti(III) has a d electron that can be excited to a higher level

Allow idea that d electrons can be excited to another level (or move between levels)

1

Absorbs one colour of light from white light

Allow idea that light is absorbed

1

Ti(IV) has no d electron so no electron transition with energy equal to that of visible light

Allow Ti(IV) has no d electrons

1

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

1

$[Cr(OH)_6]^{3-}$

1

$[CuCl_4]^{2-}$

1

(c) (i) Rapid determination of concentration

Or easy to get many readings

1

Does not use up any of the reagent/does not interfere with the reaction

Or possible to measure very low concentrations

1

(ii) Curve starts with small gradient (low rate)

1

Because negative ions collide so E_a high

1

Curve gets steeper

1

Because autocatalyst (Mn^{2+}) formed

1

Curve levels out approaching time axis

Can score this mark and next one ONLY with simple curve (that is curve with gradually decreasing gradient)

1

Because MnO_4^- ions used up

5 max

1

[15]

M3. (a) Species $[Co(H_2O)_6]^{2+}$

Precipitate $Co(H_2O)_4(OH)_2$ **1**

1

(b) $[Co(NH_3)_6]^{2+}$ **1**

(c) Reaction Oxidation **1**

Reactant Oxygen in the air **1**

(d) R Iodine **1**

Explanation $[Co(H_2O)_6]^{3+}$ oxidises I^- to I_2 **1**

[7]

M4. (a) $FeCl_3$ accepts electron pairs from water **1**

Hence acts as a Lewis acid **1**

$[Fe(H_2O)_6]^{3+}$ donates protons **1**

Hence acts as a Bronsted-Lowry acid **1**

(b) The Fe^{2+} ion has a smaller charge to size ratio **1**

Hence less polarising than Fe^{3+} or less weakening effect on O-H bonds **1**

(c) (i) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ **1**

$V_2O_4 + O_2 \rightarrow V_2O_5$ **1**

(ii) Both ions are negative or ions repel **1**

$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ Species **1**

Balanced **1**

$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ Species **1**

Balanced **1**

[13]

M5. (a) $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$ **1**

(b) $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$ **1**

(c) Moles MnO_4^- in 19.6 cm^3
= $19.6 \times 0.022 \times 10^{-3} = 4.312 \times 10^{-4}$ **1**

Moles Fe^{2+} in 25 cm^3
= $5 \times 4.312 \times 10^{-4} = 2.156 \times 10^{-3}$ **1**

Moles Fe^{2+} in 250 cm^3
= $10 \times 2.156 \times 10^{-3} = 2.156 \times 10^{-2}$ **1**

Mass Fe^{2+} = moles × A_r
A_r = 2.156 × 10^{-2} × 55.8 = 1.203 g

1

Percentage by mass of carbon
= (1.270 – 1.203) × 100/1.270
= 5.28%

1

(d) Repeat the titration and take an average of the concordant results

1

(e) Analyse several samples from different parts of the molten iron

1

[9]

M1.D

[1]

M2.D

[1]

M3.D

[1]

M4.A

[1]

M5.D

[1]

M6.C

[1]

M7.B

[1]

M8.C

[1]

M9.D

[1]

M10. (a) most powerful reducing agent: Zn; **1**

(b) (i) reducing species: Fe^{2+} **1**

(ii) oxidising species: Cl_2; **1**

(c) (i) standard electrode potential 1.25 V; **1**

(ii) equation: $Tl^{3+} + 2\ Fe^{2+} \rightarrow 2Fe^{3+} + Tl +$ balanced; **1**

correct direction; **1**

(d) (i) moles $KMnO_4 = 16.2 \times 0.0200 \times 10^{-3} = 3.24 \times 10^{-4}$; **1**

moles H_2O_2 = Moles $KMnO_4 \times 5 / 2 = 8.10 \times {}^{-4}$; **1**

8.10×10^{-4} moles H_2O_2 in 25 cm^3
$8.10 \times 10^{-4} \times 1000 / 25$ in 1000 $cm^3 = 0.0324$ mol dm^{-3}; **1**

hence g dm^{-3} = mol $dm^{-3} \times M_r = 0.0324 \times 34 = 1.10$;
(penalise use of an incorrect H_2O_2 to $KMnO_4$ ratio by two marks) **1**

(ii) $PV = nRT$; **1**

hence $V = nRT / P$
$= 8.10 \times 10^{-4} \times 8.31 \times 298/98000$; **1**

$= 2.05 \times 10^{-5}$; **1**

units m^3;

(mark consequentially to answers in (c)(i))
(allow correct answers with other units)
(answers to (c)(i) and (ii) must be to 3 significant figures; penalise once only)

1

[14]

M11. A

[1]

M12. (a) reactants brought together / increased concentration on surface or increased collision frequency **(1)**
reactants must be correctly orientated **(1)**
reaction on the surface **(1)**
products desorbed **(1)**
example of a catalysed reaction (not a named process) **(1)**
a suitable catalyst for this reaction **(1)**

penalise incorrect second reactions and catalysts

If absorption too weak reactants not brought together **(1)**
e.g. silver **(1)**
If adsorption too strong products not desorbed **(1)**
e.g. tungsten **(1)**

max 8

(b) Equations:

$Cr_2O_7^{2-} + 14\ H^+ + 6\ Fe^{2+} \rightarrow 6\ Fe^{3+} + 2\ Cr^{3+} + 7\ H_2O$ **(1)**
$Zn + 2\ Fe^{3+} \rightarrow Zn^{2+} + 2\ Fe^{2+}$ **(1)**

Method

Titrate measured volume solution against $K_2Cr_2O_7$ **(1)**

Reduce same volume solution with zinc **(1)**

Filter off excess zinc **(1)**

Titrate total Fe^{n+} using $K_2Cr_2O_7$ **(1)**

Percentage Fe^{3+} = 100 × (titre2 - titre1) / titre 2
or equivalent **(1)**

7

[15]

M13. D

[1]

M14. A

[1]

M15. (a) (i) Heterogeneous:- In a different phase to reactants **(1)**
Catalyst:- Increases reaction rate **(1)**
Alternative route or route described **(1)**
Lower E_a **(1)**
Unchanged at end of reaction **(1)** Max 4

(ii) Feature:- QoL Variable oxidation states shown by vanadium **(1)**
Equations $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ **(1)**
$2V_2O_4 + O_2 \rightarrow 2V_2O_5$ **(1)**

7

(b) $VO_2^+ + 4H^+ + 3e^- \rightarrow V^{2+}(aq) + 2H_2O$ **(1)**

$Zn \rightarrow Zn^{2+} + 2e^-$ (given)

$2VO_2^+ + 8H^+ + 3Zn \rightarrow 3Zn^{2+} + 2V^{2+}(aq) + 4H_2O$ **(1)**

2

Mol $KMnO_4$ = mv/1000 = 0.0200 × 38.5/1000 = 7.70×10^{-4} **(1)**

Mole ratio MnO_4^- to V(II) = 3:5 deduced

or equation

$5V^{2+} + 3MnO_4^- + 4H^+ \rightarrow 2H_2O + 3Mn^{2+} + 5VO_2^+$ **(2)**

Mol V(II) = $7.70 \times 10^{-4} \times 5/3$ **(1)** = 1.283×10^{-3}

Mass V = $1.283 \times 10^{-3} \times 50.9$ **(1)** = 0.0653 g

% V in sample = 0.06532 × 100/0.160 = 40.8 **(1)**

6

[15]

M16.D

[1]