**1**

(a) In each of **P** and **Q** the oxidation state of Cr is +3 / both contain $Cr^{3+}$

*If oxidation states are different lose M1 and M2*

**1**

In each of **P** and **Q** the electron configuration is the same / $d^3$ / $3d^3$

*Do not allow just same number of electrons*

**1**

Ligands are different

**1**

Different energies of (d) electrons / different split of (d) electron energy levels / different energy gap of (d) electrons / different (d) orbital energy

**1**

Different wavelengths / frequencies / energies of light / colours (of light) are absorbed (by the d electrons)

*Reference to emission and / or uv light but not to visible loses M5 and M6*

**1**

Different wavelengths / frequencies / energies of light / colours (of light) are transmitted / reflected

**1**

(b) $[Co(NH_3)_6]^{2+} + 3NH_2CH_2CH_2NH_2 \rightarrow [Co(NH_2CH_2CH_2NH_2)_3]^{2+} + 6NH_3$

*Allow $NH_2C_2H_4NH_2$ and $CH_2NH_2CH_2NH_2$*

*Allow partial substitution*

*Do not allow en or other formulae for M1 but can score M2*

**1**

4 particles form 7 particles / increase in number of particles

*Allow molecules, entities, ions, moles instead of particles*

*Do not allow atoms*

*Can score M2 if numbers match candidates incorrect equation provided number of particles increases*

**1**

disorder / entropy increases / $\Delta S$ positive

*Cannot score M3 if number of particles stated or in equation is the same or decreases*

**1**

$\Delta H$ is approx. zero / no net change in bond enthalpies

*Allow same number and type of bonds broken and formed*

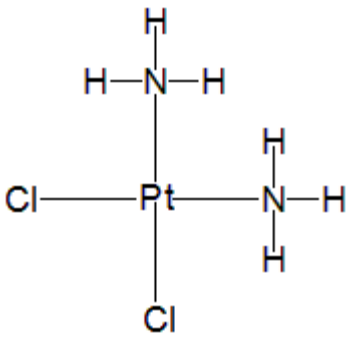
**1**

$\Delta G$ is negative / $\Delta G <= 0$

*Mark M4 and M5 independently*

**1**

(c) (i)




*Correct displayed structure*

*Must show all three N–H bonds on each N*

*Ignore arrows and lone pairs, attempt to show shape*

*Ignore charges on atoms in structure for M1*

**1**

Bond angle 90°

*Allow 87 to 93 degrees*

*Allow this angle for any complex with 4 ligands eg if $NH_2$ or Cl used instead of $NH_3$*

**1**

Charge of zero

*Award this mark if no charge shown on structure but if charges shown on ligands in M1 must state that overall charge = 0*

*Allow M3 only if cisplatin is correct OR if trans form OR if $NH_3$ not displayed OR if $NH_2$ used instead of $NH_3$*

**1**

(ii) $(NH_3)_2PtCl_2 + H_2O \rightarrow [(NH_3)_2PtCl(H_2O)]^+ + Cl^-$

*If formula of cisplatin is incorrect, mark consequentially provided*

*$H_2O$ replaces $Cl^-$ and charge on complex increases by one*

**1**

(iii) Use in small amounts / short bursts / target the application / monitor the patients

*Allow: Give patient time between doses*

**1**

(d) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ / $V_2O_5 + SO_2 \rightarrow 2VO_2 + SO_3$

*Allow multiples*

**1**

$V_2O_4 + \frac{1}{2}O_2 \rightarrow V_2O_5$ / $2VO_2 + \frac{1}{2}O_2 \rightarrow V_2O_5$

**1**

Acts as a catalyst / lowers the activation energy

**1**

Speeds up the (overall) reaction (between $SO_2$ and oxygen)

1

**[20]**

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

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]**

**3** (a) Negative ions <u>repel</u> one another

1

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

*Allow activation energy decreases.*

*Allow alternative route with lower $E_a$*

*Ignore references to heterogenous catalysis.*

1

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

*Allow multiples including fractions.*

*Ignore state symbols.*

**1**

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

*Allow multiples including fractions.*

*Ignore state symbols.*

*Allow the correct equation involving $I_3^-$*

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

**1**

**[4]**

**4**

(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 $4.3 \times 10^{14}\ s^{-1}$ / 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 $\Delta E$

*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]**

**5** (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]**

**6** (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]**

**7**

(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 = $6.95 / 277.9 = 2.5(0) \times 10^{-2}$

*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) $3(.00) \times 10^{-2}$

**1**

(d) Theoretical mass = $2.50 \times 10^{-2} \times 179.8 = 4.50$g
as long as $2.50 \times 10^{-2}$ 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 = $3.31 \times 100 / 4.50 = 73.6\%$ **(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]**

**8** (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]**

**9** (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]**

**10** (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]**

**11** (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 from reactants

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]**

**12** (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

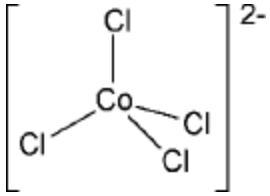
1

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

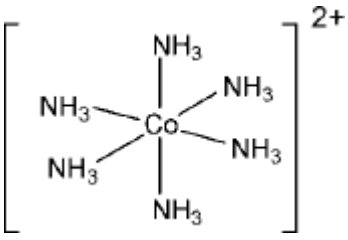
1

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]**

**13** (a) Co-ordinate / dative / dative covalent / dative co-ordinate

*Do not allow covalent alone*

**1**

(b) (lone) pair of electrons on oxygen/O

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

**1**

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

*'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 = $4.31 \times 10^{-4}$

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

*Allow $4.3 \times 10^{-4}$ ( 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 × $4.31 \times 10^{-4}$

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

**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 (= $7.68 \times 10^{-3}$)
for M5 % of $FeC_2O_4.2H_2O$ = (M3 ans/above M4ans) × 100)

eg using correct ratio 5/3:

Moles of $FeC_2O_4 = 5/3 \times 4.31 \times 10^{-4} = 7.19 \times 10^{-4}$

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 $FeC_2O_4.2H_2O = 1.29 \times 100/1.381 = 93.4$ (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*** $= 5/2 \times 4.31 \times 10^{-4} = 1.078 \times 10^{-3}$

***M3*** $= 1.0078 \times 10^{-3} \times 10 = 1.078 \times 10^{-2}$

***M4*** $= 1.078 \times 10^{-2} \times 179.8 = 1.94$ g

***M5*** $= 1.94 \times 100/1.381 = 140$ % (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]**