**Q15.**

This question explores some reactions and some uses of cobalt compounds.

(a) Ethanal is oxidised to ethanoic acid by oxygen. The equation for this reaction is

$$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$$

This redox reaction is slow at room temperature but speeds up in the presence of cobalt compounds.

Explain why a cobalt compound is able to act as a catalyst for this process.

Illustrate your explanation with **two** equations to suggest how, in the presence of water and hydrogen ions, $Co^{3+}$ and then $Co^{2+}$ ions could be involved in catalysing this reaction.

**(4)**

(b) In aqueous solution, the $[Co(H_2O)_6]^{2+}$ ion reacts with an excess of ethane-1,2-diamine to form the complex ion **Y**.

(i) Write an equation for this reaction.

Explain, in terms of the chelate effect, why the complex ion **Y** is formed in preference to the $[Co(H_2O)_6]^{2+}$ complex ion.

**(3)**

(ii) Draw a diagram that shows the shape of the complex ion **Y** and shows the type of bond between the ethane-1,2-diamine molecules and the cobalt.

**(3)**

(c) Compound **Z** is a complex that contains only cobalt, nitrogen, hydrogen and chlorine.

A solid sample of **Z** was prepared by reaction of 50 cm$^3$ of 0.203 mol dm$^{-3}$ aqueous cobalt(II) chloride with ammonia and an oxidising agent followed by hydrochloric acid.

When this sample of **Z** was reacted with an excess of silver nitrate, 4.22 g of silver chloride were obtained.

Use this information to calculate the mole ratio of chloride ions to cobalt ions in **Z**.

Give the formula of the complex cobalt compound **Z** that you would expect to be formed in the preparation described above.

Suggest **one** reason why the mole ratio of chloride ions to cobalt ions that you have calculated is different from the expected value.

**(5)**

**(Total 15 marks)**

**Q16.**

Iron(II) ethanedioate is another insoluble solid used as a pigment in paints and glass. It occurs as a dihydrate ($FeC_2O_4.2H_2O$). One procedure used for the preparation of iron(II) ethanedioate is outlined below.

**Procedure**

A 6.95 g sample of hydrated iron(II) sulfate ($FeSO_4.7H_2O$) was added to 100 $cm^3$ of water in a beaker and stirred until all of the solid dissolved. A 150 $cm^3$ volume of 0.20 mol $dm^{-3}$ sodium ethanedioate solution was added to the beaker. The mixture was stirred until precipitation was complete. After filtration, 3.31 g of the dihydrate ($FeC_2O_4.2H_2O$) were collected.

(a) Write an equation for the reaction between iron(II) sulfate and sodium ethanedioate.

**(1)**

(b) Calculate the amount, in moles, of $FeSO_4.7H_2O$ in 6.95 g of hydrated iron(II) sulfate. Show your working.

**(2)**

(c) Calculate the amount, in moles, of sodium ethanedioate in 150 $cm^3$ of 0.20 mol $dm^{-3}$ sodium ethanedioate solution.

**(1)**

(d) Calculate the percentage yield of iron(II) ethanedioate dihydrate ($M_r$ = 179.8) formed in this reaction.
Give your answer to the appropriate precision. Show your working.

**(2)**

(e) In this experiment, no side reactions take place, the reagents are pure and the reaction goes to completion.

Suggest **one** reason why the yield of iron(II) ethanedioate dihydrate in this experiment is less than 100%.

**(1)**

(f) When dissolved in dilute sulfuric acid, the number of moles of ethanedioate ions in a pigment can be determined by titration with acidified potassium manganate(VII).

Explain why the titration of a sample of iron(II) ethanedioate would require a different amount of potassium manganate(VII) than a titration of an equimolar amount of copper(II) ethanedioate.

**(2)**

**(Total 9 marks)**

## Q17.

Transition metal compounds have a range of applications as catalysts.

(a) State the general property of transition metals that allows the vanadium in vanadium(V) oxide to act as a catalyst in the Contact Process.

**(1)**

(b) Write **two** equations to show how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1

Equation 2

**(2)**

(c) In the Contact Process, vanadium(V) oxide acts as a heterogeneous catalyst.

(i) Give the meaning of the term *heterogeneous*.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**(1)**

(ii) Give **one** reason why impurities in the reactants can cause problems in processes that use heterogeneous catalysts.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**(1)**

(d) The oxidation of $C_2O_4^{2-}$ ions by $MnO_4^-$ ions in acidic solution is an example of a reaction that is autocatalysed.

(i) Give the meaning of the term *autocatalysed*.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**(1)**

(ii) Identify the autocatalyst in this reaction.

______________________________________________________________________

**(1)**

(iii) Write **two** equations to show how the autocatalyst is involved in this oxidation of $C_2O_4^{2-}$ ions.

Equation 1

______________________________________________________________________

Equation 2

______________________________________________________________________

**(2)**

**(Total 9 marks)**

**Q18.**

(a) Explain the meaning of the terms *ligand* and *bidentate* as applied to transition metal complexes.

**(2)**

(b) Aqueous cobalt(II) ions react separately with an excess of chloride ions and with an excess of ammonia.

For each reaction, draw a diagram to illustrate the structure of, the shape of and the charge on the complex ion formed.

In each case, name the shape and indicate, on the diagram, a value for the ligand-metal-ligand bond angle.

**(6)**

(c) The complex ion formed in aqueous solution between cobalt(II) ions and chloride ions is a different colour from the $[Co(H_2O)_6]^{2+}$ ion.

Explain why these complex ions have different colours.

**(3)**

(d) In aqueous ammonia, cobalt(II) ions are oxidised to cobalt(III) ions by hydrogen peroxide. The $H_2O_2$ is reduced to hydroxide ions.

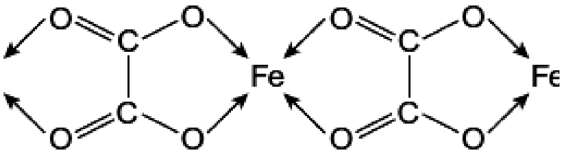
Calculate the minimum volume of 5.00 mol $dm^{-3}$ $H_2O_2$ solution required to oxidise the $Co^{2+}$ ions in 9.87 g of $CoSO_4.7H_2O$

**(5)**

**(Total 16 marks)**

**Q19.**

Solid iron(II) ethanedioate dihydrate ($FeC_2O_4.2H_2O$) has a polymeric structure.
Two repeating units in the polymer chain are shown.



Each iron ion is also bonded to two water molecules. These are **not** shown in the diagram.

(a) Name the type of bond that is represented by the arrows.

____________________________________________________________

**(1)**

(b) In terms of electrons explain how the water molecules, **not** shown in the diagram, form bonds to the iron.

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

**(2)**

(c) Predict the value of the bond angle between the two bonds to iron that are formed by these two water molecules.

____________________________________________________________

**(1)**

(d) Iron(II) ethanedioate dihydrate can be analysed by titration using potassium manganate(VII) in acidic solution. In this reaction, manganate(VII) ions oxidise iron(II) ions and ethanedioate ions.

A 1.381 g sample of impure $FeC_2O_4.2H_2O$ was dissolved in an excess of dilute sulfuric acid and made up to 250 $cm^3$ of solution.
25.0 $cm^3$ of this solution decolourised 22.35 $cm^3$ of a 0.0193 mol $dm^{-3}$ solution of potassium manganate(VII).

(i) Use the half-equations given below to calculate the reacting ratio of moles of manganate(VII) ions to moles of iron(II) ethanedioate.

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

$$Fe^{2+} \longrightarrow Fe^{3+} + e^-$$

$$C_2O_4^{2-} \longrightarrow 2CO_2 + 2e^-$$

________________________________________

________________________________________

________________________________________

**(1)**

(ii) Calculate the percentage by mass of $FeC_2O_4.2H_2O$ in the original sample.

(If you have been unable to answer part (d)(i) you may assume that three moles of manganate(VII) ions react with seven moles of iron(II) ethanedioate. This is **not** the correct ratio.)

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**(5)**
**(Total 10 marks)**

## Q20.

You may find the following electrode potential data helpful when answering this question.

| Electrode half-equation | $E^\ominus$ / V |
|---|---|
| $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$ | +1.33 |
| $O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$ | +1.23 |
| $Cr^{3+}(aq) + e^- \longrightarrow Cr^{2+}(aq)$ | –0.44 |
| $Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$ | –0.76 |
| $Cr^{2+}(aq) + 2e^- \longrightarrow Cr(s)$ | –0.91 |

(a) Describe the colour changes that you would observe when an excess of zinc is added to an acidified solution of potassium dichromate(VI) in the absence of air.

For each colour change, identify the coloured ions responsible and write an equation for each reaction that occurs with zinc.
In the equations, you should represent the ions in their simplest form, for example $Cr^{3+}$.

**(5)**

(b) Describe what you would observe when dilute aqueous sodium hydroxide is added, dropwise until in excess, to a dilute aqueous solution containing chromium(III) ions.

Write **two** equations to illustrate your observations.
In these equations you should give the full formula of each of the complexes, for example $[Cr(H_2O)_6]^{3+}$.

**(4)**

(c) When an aqueous solution containing $[Cr(H_2O)_6]^{3+}$ ions is warmed in the presence of $Cl^-$ ions, $[Cr(H_2O)_5Cl]^{2+}$ ions are formed and the colour of the solution changes.

Name this type of reaction.

Suggest, in terms of electrons, why the colours of the complex ions are different.

**(3)**

(d) The chromium(II) ion $[Cr(H_2O)_6]^{2+}$ has different properties from the $[Cr(H_2O)_6]^{3+}$ ion.

Use data from the table above to explain why, in an open container, $[Cr(H_2O)_6]^{2+}(aq)$ ions change into $[Cr(H_2O)_6]^{3+}(aq)$ ions.

Suggest the identity of the products formed in each case when sodium carbonate solution is added to separate solutions containing $[Cr(H_2O)_6]^{2+}(aq)$ ions and $[Cr(H_2O)_6]^{3+}(aq)$ ions.

Explain why the $[Cr(H_2O)_6]^{3+}(aq)$ ions behave differently from the $[Cr(H_2O)_6]^{2+}(aq)$ ions.

In your answer to this part of the question, equations are **not** required.

**(7)**

**(Total 19 marks)**

## Mark Scheme

## Q15.

(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]**

## Q16.

(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]**

## Q17.

(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

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

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]**

## Q18.

(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

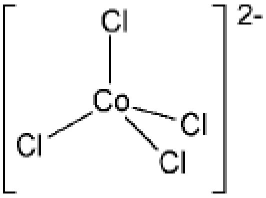
1

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

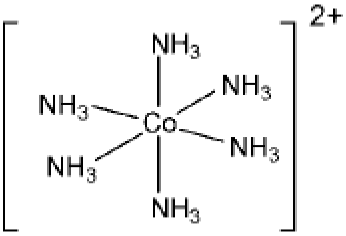
1

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]**

## Q19.

(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 = $\underline{4.31 \times 10^{-4}}$
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 × $4.31 \times 10^{-4}$

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

1

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

***M4*** *= $1.006 \times 10^{-2}$ × 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 × $4.31 \times 10^{-4}$ = $7.19 \times 10^{-4}$
Moles of $FeC_2O_4$ in 250 $cm^3$ = $7.19 \times 10^{-4}$ × 10 = $7.19 \times 10^{-3}$
Mass of $FeC_2O_4.2H_2O$ = $7.19 \times 10^{-3}$ × 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 × $4.31 \times 10^{-4}$ = $1.078 \times 10^{-3}$*

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

***M4*** *= $1.078 \times 10^{-2}$ × 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]**

## Q20.

(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 <u>d</u> electrons are <u>different</u> (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 water

*Ignore charge/size ratio and mass/charge*

**1**

**[19]**