**3(a)(i)**

**M1** Heat (solid **FA 5)**
**AND**
observe condensation, droplets, steam, water vapour

**M2** Make an aqueous solution of **FA 5 /** dissolve in water to use for tests

**M3** (To portion of the solution) add aqueous $NH_3$
**AND**
white ppt **AND** insoluble in excess $NH_3$

**M4** (To portion of the solution) add aqueous barium chloride or barium nitrate
**AND**
white precipitate

**M5** to distinguish sulfate / sulfite
(white precipitate from **M4**) insoluble in hydrochloric **OR** nitric acid
**OR**
$KMnO_4$ is not decolourised / remains purple (added after **M4** or directly to **FA 5** (aq))

**3(a)(ii)**

| | |
|---|---|
| $Zn^{2+}$ | X |
| $SO_4^{2-}$ | ✓ |
| $H_2O$ | ✓ |

**3(b)(i)**

- (**FA 6**) starting colour purple
- solid jumps / moves around
- black residue
- test with glowing splint
- splint relights / glows more brightly

**3(b)(ii)**

(dark) Green

**3(c)(i)**

'No change' 2 correct = *, 3 correct = **

2* = 1 mark

Max mark = 4

| *test* | *observations* | | |
|---|---|---|---|
| | **FA 7** | **FA 8** | **FA 9** |
| **Test 1**<br>Add<br>hydrogen peroxide | Bubbles/ effervescence *<br><br>Purple / **FA 7** (solution) to colourless (solution) *<br><br>(Gas / oxygen) relights glowing splint * | No change | Bubbles / effervescence *<br><br>(Gas/ oxygen) relights glowing splint * |
| **Test 2**<br>Add<br>sodium hydroxide,<br>then | | Off-white ppt* | No change |
| leave to stand | | brown ppt on standing* | |
| **Test 3**<br>Add aqueous<br>iron(II) sulfate | Turns colourless / yellow **OR** colourless / yellow solution formed* | No change | |

**3(c)(ii)**

manganese / Mn





**3(c)(iii)**

| | **FA 6 / FA 7** | **FA 8** |
|---|---|---|
| oxidation state | (+)7 | (+)2 |



**3(a)(i)**

2 * = 1 mark (round down). Max 5 marks.

| *test* | *observations* | |
|---|---|---|
| | **FA 4** | **FA 5** |
| 1<br>+ NaOH(aq) | red-brown / brown ppt<br>**AND**<br>insoluble in excess * | white ppt *<br>soluble in excess * |
| 2<br>+ $NH_3$(aq) | red-brown / brown ppt<br>**AND**<br>insoluble in excess * | white ppt<br>**AND**<br>insoluble in excess * |
| 3<br>+ $Na_2CO_3$(aq) | fizzing *<br>gas gives white ppt with limewater *<br>red-brown ppt * | white ppt *<br>fizzing *<br>gas gives white ppt with limewater (award if not awarded for **FA 4**) |
| 4<br>+ $BaCl_2$(aq) /<br>$Ba(NO_3)_2$(aq) | white ppt **AND** | white ppt * |
| 5<br>+ $H^+$ / $KMnO_4$(aq) | stays purple / no change **AND** | stays purple / no change * |

**3(a)(ii)**

| *ions* | **FA 4** | **FA 5** |
|---|---|---|
| cations | $Fe^{3+}$; $H^+$ | $Al^{3+}$ |
| anions | $SO_4^{2-}$ | $SO_4^{2-}$ |

5 ions correct = 3 marks
3 or 4 ions correct = 2 marks
2 ions correct = 1 mark

**3(b)(i)**

2 * = 1 mark (round down)

| *test* | *observations* | |
|---|---|---|
| | **FA 6** | **FA 7** |
| 1<br>+ $H^+$ / $KMnO_4$(aq) | (turns paler pink) | (purple fades slightly) |
| and warm | decolourises / turns colourless / turns (pale) yellow * | decolourises / turns colourless / turns (pale) yellow * |
| 2<br>+ $I_2$(aq) + NaOH<br>(and warm) | no change * | ppt * that is (pale) yellow * |
| 3<br>+ $Na_2CO_3$(aq) | fizzing * | no change * |

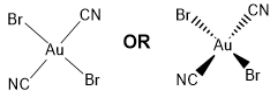
| | |
|---|---|
| 3(b)(ii) | **M1** (**FA 6** is) methanoic acid because it produces $CO_2$ / reacts with sodium carbonate<br>**AND** it can be oxidised / it reacts with $KMnO_4$<br><br>**M2** (**FA 7** is) propan-2-ol as it gives a ppt in test 2<br>**OR** gives a positive tri-iodomethane/iodoform test<br>**OR** has the $-CH(OH)CH_3$ group |
| 3(c) | Correct equation<br>$CH_3CH_2COOH + CH_3CH_2OH \rightarrow CH_3CH_2COOCH_2CH_3 + H_2O$<br>**OR**<br>$C_2H_5COOH + C_2H_5OH \rightarrow C_2H_5COOC_2H_5 + H_2O$ |



| | |
|---|---|
| 3(a)(i) | • selects (aqueous) silver nitrate and (aqueous) ammonia *<br>• white ppt *<br>• soluble in (aqueous) ammonia *<br>• NaCl *<br><br>2 * = 1 mark |
| 3(a)(ii) | (The acid) removes / reacts with the hydrogencarbonate ions **OR** silver ions react with hydrogencarbonate ions |
| 3(b)(i) | • green (at start) *<br>• turns to a black powder / solid *<br>• powder very fluid / moves around the test-tube *<br>• condensation (on walls of test-tube) *<br><br>2 * = 1 mark |
| 3(b)(ii) | • forms green-blue solution *<br>• effervescence *<br>• vigorous reaction *<br>• attempts to test with limewater *<br>• gas / carbon dioxide gives white precipitate / solid with limewater *<br><br>2 * = 1 mark |
| 3(b)(iii) | **Test 1** Add NaOH(aq): (pale) blue precipitate insoluble in excess *<br>**Test 2** Add $NH_3$(aq): (pale) blue precipitate * (precipitate dissolves forming) dark / deep blue solution in excess *<br>**Test 3** Add aluminium foil: effervescence / fizzing* (gas) pops with a lighted splint * pink-brown solid * turns colourless / pale blue solution formed * gets hotter *<br>Metal ion in **FB 7**: $Cu^{2+}$ *<br><br>2 * = 1 mark |
| 3(c)(i) | **Test 1** Add NaOH(aq): green precipitate * insoluble in excess * (precipitate) turns brown (on surface) *<br>**Test 2** Add acidified $KMnO_4$: purple to colourless / (pale) yellow solution **OR** $KMnO_4$ decolourised*<br><br>2 * = 1 mark<br>Metal ion in **FB 8**: $Fe^{2+}$ |
| 3(c)(ii) | Redox reaction<br>**AND** change to colourless linked to reduction of manganate(VII) ions **OR** change to yellow colour linked to oxidation of $Fe^{2+}$ or production of $Fe^{3+}$. |





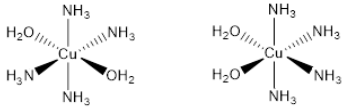
| | |
|---|---|
| 5(a) | species / number of **unpaired** electrons: 3d / 4s<br>Cu: 0 / 1<br>$Cu^{2+}$: 1 / 0 |
| 5(b) | • five 3d orbitals (lines, boxes) in the isolated $Cu^{2+}$ ion of the same energy<br>• splitting: three higher and two lower d orbitals<br>• energy of all five d orbitals in complex higher than all d orbitals in isolated ion<br><br>any two [1], all three [2] |
| 5(c) | **M1:** more than one (stable) oxidation state / exist in variable oxidation states<br><br>**M2:** vacant / empty (d) orbitals are energetically accessible<br>**OR** vacant / empty (d) orbitals can form dative bonds with ligands |
| 5(d) | metal ion / coordination number / formula of complex ion / charge of complex ion<br>$Ag^+$ / 2 / $Ag(CN)_2$ / 1–<br>$Fe^{2+}$ / 6 / $Fe(CN)_6$ / 4–<br>each row [1] |
| 5(e) | **M1:**  <br><br>**M2:** (shape) square planar **AND** (bond angle) 180° |
| 5(f)(i) | **M1**: moles $MnO_4^- = 0.075 \times 0.0225 = 1.6875 \times 10^{-3}$<br><br>**M2:** moles $V^{2+} = 5 / 3 \times 1.6875 \times 10^{-3} = 2.8125 \times 10^{-3}$<br><br>**M3:** mass V $= 50.9 \times 2.8125 \times 10^{-3} = 0.143$ g<br>% of V $= 0.143 / 0.250 \times 100 = 57.3$ min 2sf |
| 5(f)(ii) | $2VO_3^- + 3Zn + 12H^+ \rightarrow 2V^{2+} + 3Zn^{2+} + 6H_2O$<br><br>**M1:** 2 : 3 ratio on both sides<br><br>**M2:** rest of the equation correct |



| | |
|---|---|
| 5(a)(i) | $Co^{2+}$ = [Ar] $3d^7$ **AND** $Co^{3+}$ = [Ar] $3d^6$ |
| 5(a)(ii) | has vacant d orbitals that are energetically accessible |
| 5(a)(iii) | • pink<br>• blue<br>• aqueous<br><br>Any two [1], all three [2] |
| 5(a)(iv) | $[Co(H_2O)_6]^{2+} + 4HCl \rightarrow [CoCl_4]^{2-} + 6H_2O + 4H^+$ **OR** $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$ |

| | |
|---|---|
| 5(a)(v) | ligand exchange |
| 5(a)(vi) | $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2(H_2O)_4 + 2H_2O$ **OR**<br>$[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$ |
| 5(b)(i) | **M1:** Nernst equation $E = E^{\ominus} + (0.059 / z) \times \log(\frac{[\text{oxidised}]}{[\text{reduced}]})$<br>**M2:** E = –0.28 + (0.059 / 2) × log(0.02) |
| 5(b)(ii) | 1.66 V |
| 5(b)(iii) | $3Co + Cr_2O_7^{2-} + 14H^+ \rightarrow 3Co^{2+} + 2Cr^{3+} + 7H_2O$ |
| 5(b)(iv) | $Co^{2+}$ / Co, $Co^{2+}$ / Co, $Cr_2O_7^{2-}$ / $Cr^{3+}$ |
| 5(c) | **M1:** moles of cobalt = 0.547 / 58.9 = 0.00929<br>**M2:** coulombs required = 0.00929 × 96500 × 2 = 1792<br>**M3:** time required = 1792 / 0.50 = 3584.8 s = 59.7 minutes 3sf |



| | |
|---|---|
| 1(a) | forms (one or more) stable ions / compounds / oxidation states<br>with incomplete / partially filled (3)d orbital(s) / d shell / d sub-shell |
| 1(b)(i) | (orbitals) are at the same energy |
| 1(b)(ii) | $(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$ |
| 1(c)(i) | $[Cu(NH_3)_4(H_2O)_2]^{2+}(aq)$ deep / dark / royal blue<br>**AND**<br>$[CuCl_4]^{2-}(aq)$ yellow |
| 1(c)(ii) | **M1:** d orbital(s) of different energy / d-d splitting occurs / d sub-shell splits<br>**M2:** electron(s) promoted / excited<br>**M3:** light / wavelength / frequency / photon absorbed **AND** complementary colour seen |
| 1(d)(i) | **M1:** ligand exchange / replacement / substitution / displacement<br>**M2:** $[CuCl_4]^{2-} + 4NH_3 + 2H_2O \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4Cl^-$ |
| 1(d)(ii) | **M1:** one correct 3D structure of $[Cu(H_2O)_2(NH_3)_4]^{2+}$<br>**M2:** correct 3D stereoisomer structure of isomer 1<br>   |
| 1(d)(iii) | cis isomer **AND** dipoles do not cancel |
| 1(e)(i) | (two) oxygen and (one) nitrogen (can donate) three lone pair(s) of electrons (to the metal ion) |





| | |
|---|---|
| 1(e)(ii) | $[Co(C_4H_5NO_4)_2]^-$ |
| 1(f)(i) | equilibrium constant for the formation of the complex (ion)<br>in a solvent / water / solution **OR** from its constituent ions or molecules |
| 1(f)(ii) | $[Ag(CN)_2]^-$(aq) **AND** largest (value of) $K_{stab}$ |
| 1(g) | **M1 M2:** any two [1], all four [2]<br>• moles $MnO_4^-$ = 0.015 ×18.70/1000 = $2.805 \times 10^{-4}$<br>• moles $SO_3^{2-}$ = $2.805 \times 10^{-4}$ × 5/2 = $7.0125 \times 10^{-4}$ (in 10 $cm^3$)<br>• moles $SO_3^{2-}$ = $1.753 \times 10^{-2}$ (in 250 $cm^3$)<br>• mass $Na_2SO_3$ = $1.753 \times 10^{-2}$ × 126.1 = 2.21 g<br>**M3:** % purity = 100 × 2.21 / 3.75 = **58.9 – 59.0 %** min 2sf |