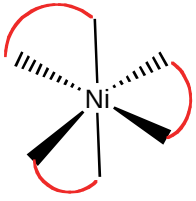
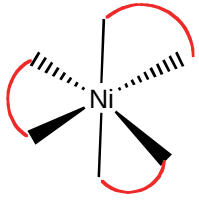
Question			Answer	Marks	Guidance
1	(a)		(+)5 ✓	1	**ALLOW** 5+ **OR** V **OR** Cr^{5+}
1	(b)		For equations, **IGNORE** any state symbols; **ALLOW** multiples --- Any correct equation for a reaction catalysed by a transition element, compound or ion **AND** transition element, compound or ion (by formula or name) ✓	1	**EXAMPLES** $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (allow →) **AND** Fe/iron oxide $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (allow →) **AND** V_2O_5/Pt $2CO + 2NO \rightarrow 2CO_2 + N_2$ **AND** Pt/Pd/Rh/Au Equation for any alkene + H_2 → alkane **AND** Ni/Pt/Pd $C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$ **AND** Fe/$FeCl_3$/Fe^{3+} $C_6H_6 + Br_2 \rightarrow C_6H_5Br + HBr$ **AND** Fe/$FeBr_3$/Fe^{3+} $2H_2O_2 \rightarrow 2H_2O + O_2$ **AND** MnO_2 For other examples, **CHECK** with TL
1	(c)	(i)	**Donates two** electron **pairs** (to a metal ion) **AND** forms **two** coordinate **bonds** (to a metal ion) ✓ ***NOTE:*** *Metal ion not required as* Ni^{3+} *is in the question*	1	**ALLOW** lone pairs for electron pairs **ALLOW** dative (covalent) bonds for coordinate bonds **TWO** is only needed once, e.g. **Donates two** electron **pairs** to form coordinate **bonds** **Donates** electron **pairs** to form **two** coordinate **bonds**
1	(c)	(ii)	$C_3H_{10}N_2$ ✓	1	**ALLOW** in any order **IGNORE** structure
1	(c)	(iii)	**MARK INDEPENDENTLY** --- $H_2NCH_2CH_2CH_2NH_2$ ✓ Each N **OR** each NH_2 **OR** amine group has a lone pair/electron pair **OR** lone pairs shown on N atoms in structure ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** $H_2NCH_2CH(CH_3)NH_2$ **OR** $H_2NCH(CH_2CH_3)NH_2$ **ALLOW** secondary or tertiary diamines or mixture **IGNORE** complex ion For other examples, **CHECK** with TL

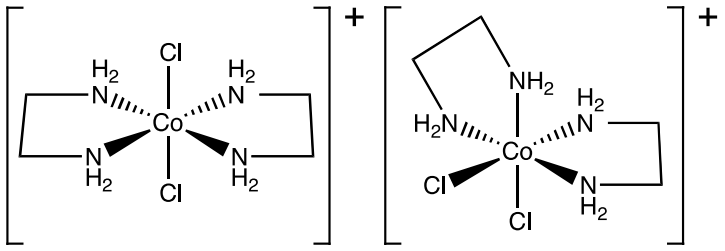
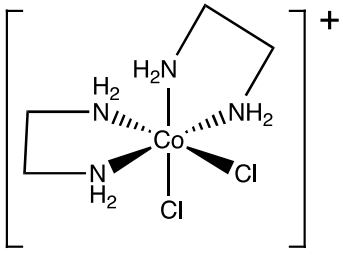
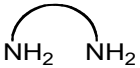
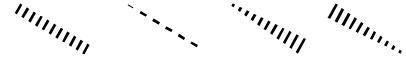
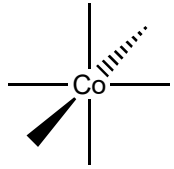
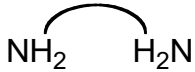
Question			Answer	Marks	Guidance
1	(c)	(iv)	6 ✓	1	
1	(c)	(v)	3–D diagrams of **BOTH** optical isomers required for the mark  **AND**  ✓	1	In this part, Charge **AND** Square brackets **NOT** required **IGNORE** N or attempts to draw structure of bidentate ligand Other orientations possible but all follow same principle with 2nd structure being a mirror image of the first

Question			Answer	Marks	Guidance
1	(d)		*Quality of written communication* Observation must be linked to the correct **reaction** ***REACTIONS OF AQUEOUS Cu^{2+}*** --- **REACTION OF Cu^{2+} with NaOH(aq)** **Correct balanced equation** $Cu^{2+}(aq) + 2OH^-(aq) \longrightarrow Cu(OH)_2(s)$ ✓ state symbols **not** required **Observation** blue precipitate/solid ✓	**2**	***FULL ANNOTATIONS MUST BE USED THROUGHOUT*** **ALLOW some reactions for Cu^{2+} and some for Co^{2+}** **ALLOW equilibrium signs in all equations** **IGNORE any incorrect initial colours** **IGNORE state symbols** **IGNORE an incorrect formula for an observation** --- **ALLOW** $[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow Cu(OH)_2(H_2O)_4 + 2H_2O$ **ALLOW** full or 'hybrid' equations, e.g. $Cu^{2+} + 2NaOH \rightarrow Cu(OH)_2 + 2Na^+$ $[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow Cu(OH)_2 + 6H_2O$ $_4 + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$ **ALLOW** any shade of blue CuSO
1	(d)		**REACTION OF Cu^{2+} WITH excess NH_3(aq)** **Correct balanced equation** $[Cu(H_2O)_6]^{2+} + 4NH_3 \longrightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$ ✓ **Observation** deep/dark blue (solution) ✓	**2**	**IGNORE initial precipitation of $Cu(OH)_2$** **IGNORE** $[Cu(NH_3)_4]^{2+}$ **ALLOW** royal blue, ultramarine blue or any blue colour that is clearly darker than for $[Cu(H_2O)_6]^{2+}$ **DO NOT ALLOW** deep blue precipitate for observation
1	(d)		**REACTION OF Cu^{2+} WITH HCl(aq)** **Correct balanced equation** $[Cu(H_2O)_6]^{2+} + 4Cl^- \longrightarrow [CuCl_4]^{2-} + 6H_2O$ ✓ **Observation** yellow (solution) ✓	**2**	**IGNORE** mention of different concentrations of HCl **ALLOW** $CuCl_4^{2-}$ i.e. no brackets **OR** $Cu(Cl)_4^{2-}$ **ALLOW** $[Cu(H_2O)_6]^{2+} + 4HCl \longrightarrow [CuCl_4]^{2-} + 6H_2O + 4H^+$ **IGNORE** $Cu^{2+} + 4Cl^- \longrightarrow CuCl_4^{2-}$ **ALLOW** green–yellow **OR** yellow–green **DO NOT ALLOW** yellow precipitate for observation

Question			Answer	Marks	Guidance
1	(d)		*Quality of written communication* Observation must be linked to the correct **reaction** ***REACTIONS OF AQUEOUS Co^{2+}*** --- **REACTION OF Co^{2+} with NaOH(aq)** **Correct balanced equation** $Co^{2+}(aq) + 2OH^-(aq) \longrightarrow Co(OH)_2(s)$ ✓ state symbols **not** required **Observation** blue precipitate/solid ✓	**2**	***FULL ANNOTATIONS MUST BE USED THROUGHOUT*** **ALLOW some reactions for Cu^{2+} and some for Co^{2+}** **ALLOW equilibrium signs in all equations** **IGNORE any incorrect initial colours** **IGNORE state symbols** **IGNORE an incorrect formula for an observation** --- **ALLOW** $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2(H_2O)_4 + 2H_2O$ **ALLOW** full or 'hybrid' equations, e.g. $Co^{2+} + 2NaOH \rightarrow Co(OH)_2 + 2Na^+$ $[Co(H_2O)_6]^{2+} + 2OH^- \rightarrow Co(OH)_2 + 6H_2O$ $_4 + 2NaOH \rightarrow Co(OH)_2 + Na_2SO_4$ **ALLOW** any shade of blue CoSO **IGNORE** changes in colour over time
1	(d)		**REACTION OF Co^{2+} WITH excess NH_3(aq)** **Correct balanced equation** $[Co(H_2O)_6]^{2+} + 6NH_3 \longrightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ ✓ **Observation** brown/yellow (solution) ✓	**2**	**IGNORE initial precipitation of $Co(OH)_2$** **ALLOW** any shade of brown or yellow **DO NOT ALLOW** brown/yellow precipitate for observation
1	(d)		**REACTION OF Co^{2+} WITH HCl(aq)** **Correct balanced equation** $[Co(H_2O)_6]^{2+} + 4Cl^- \longrightarrow [CoCl_4]^{2-} + 6H_2O$ ✓ **Observation** blue (solution) ✓	**2**	**IGNORE** mention of different concentrations of HCl **ALLOW** $CoCl_4^{2-}$ i.e. no brackets **OR** $Co(Cl)_4^{2-}$ **ALLOW** $[Co(H_2O)_6]^{2+} + 4HCl \longrightarrow [CoCl_4]^{2-} + 6H_2O + 4H^+$ **IGNORE** $Co^{2+} + 4Cl^- \longrightarrow CoCl_4^{2-}$ **ALLOW** any shades of blue **DO NOT ALLOW** blue precipitate for observation
			Total	**14**	

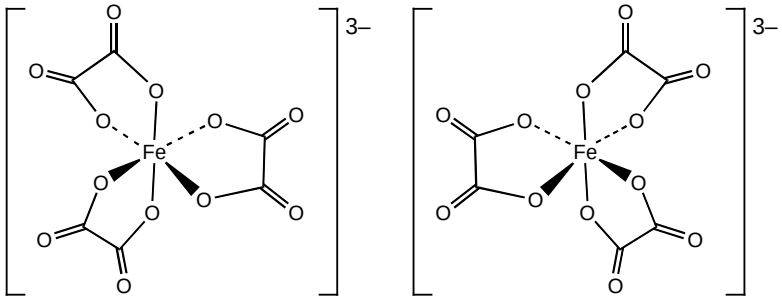
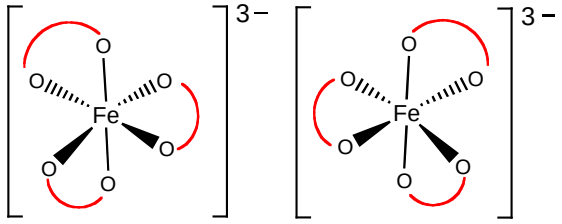
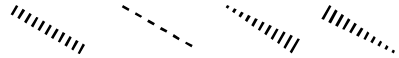
Question			Answer	Marks	Guidance
2	(a)		(Transition element) has **an ion** with an incomplete/partially-filled d **sub-shell/d-orbital** ✓ Scandium/Sc and zinc/Zn are not transition elements ✓ *Electron configurations of ions* Sc^{3+} **AND** $1s^2 2s^2 2p^6 3s^2 3p^6$ ✓ Zn^{2+} **AND** $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ ✓ Sc^{3+} **AND** d **sub-shell** empty **/ d orbital(s) empty** ✓ ***Note**: Sc^{3+} must be the **ONLY** scandium ion shown for this mark* Zn^{2+} **AND** d **sub-shell** full **/ALL d-orbitals** full ✓ ***Note**: Zn^{2+} must be the **ONLY** zinc ion shown for this mark*	**6**	***FULL ANNOTATIONS MUST BE USED*** **----------** **ALLOW** capital **'**D' within definition **DO NOT ALLOW** d shell **ALLOW** if **ONLY** Sc and Zn are used to illustrate d block elements that are **NOT** transition elements This can be from anywhere in the overall response in terms of Sc, Sc^{3+}, Zn, Zn^{2+} **OR** incorrect charges, i.e. only Sc^{+}, Sc^{2+}, Zn^{+} In electron configurations, **IF** subscripts **OR** caps used, **DO NOT ALLOW** when first seen but credit subsequently **ALLOW** $4s^0$ in electron configurations **IGNORE** [Ar] **IGNORE** electron configurations for other Sc and Zn ions **ALLOW** for Sc^{3+}: Sc forms a 3+ ion; **ALLOW** Sc^{+3} **ALLOW** for Zn^{2+}: Zn forms a 2+ ion; **ALLOW** Zn^{+2} **ALLOW** Sc^{3+} has no d sub-shell **DO NOT ALLOW** 'd sub-shell is incomplete' *(in definition)* **DO NOT ALLOW** 'd sub-shell is incomplete' *(in definition)*

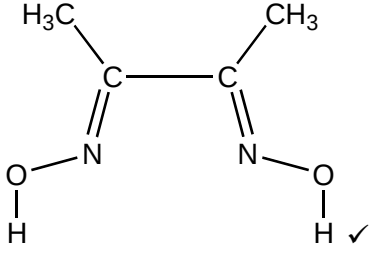
	(b)	**(i)**	Donates **two** electron/lone pairs to a metal ion **OR** Co^{3+} ✓ ***DO NOT ALLOW*** *metal (complex contains* Co^{3+}*)* Electron/lone pair on N **OR** NH_2 (groups) ✓	 **2**	**ALLOW** 'forms **two** coordinate bonds/dative covalent/dative bonds' as an alternative for 'donates **two** electron/lone pairs' *Two is required for 1st marking point* *Two can be implied using words such as 'both' or 'each'* For metal ion, **ALLOW** transition (metal) ion Second mark is for the atom that donates the electron/lone pairs **ALLOW** both marks for a response that communicates the same using N as the focus: e.g. The two N atoms each donate an electron pair to metal ion
	(b)	**(ii)**	$[Co(H_2NCH_2CH_2NH_2)_2Cl_2]^+$ ✓	**1**	Square brackets **AND** + charge required **DO NOT ALLOW** any charges included within square brackets **ALLOW** $[Co(C_2H_8N_2)_2Cl_2]^+$ **OR** $[CoC_4H_{16}N_4Cl_2]^+$ **ALLOW** structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **IGNORE** $[Co(en)_2Cl_2]^+$ *simplifies question* Within formula, **ALLOW** ….$(Cl)_2$, (Cl_2) **ALLOW** CO Within the context of the question, CO is Co
	(b)	**(iii)**	6 ✓	**1**	

	(b)	**(iv)**	 ✓ ✓  ✓ Note: For each structure, **ALL** NH_2 groups must be shown **AND** bonding between Co **AND** N of NH_2. For $H_2NCH_2CH_2NH_2$, **ALLOW** C–C without Hs and  --- **IF** NH_2 shown without Hs, e.g.  , penalise first time **ONLY** --- **IF ALL** 3 isomers are 'correct', but 2 x Cl **AND** no Ns, e.g.  **AWARD** 1 mark	**3**	***FULL ANNOTATIONS MUST BE USED*** --- **IGNORE** charges (**anywhere**) and labels (even if wrong) Square brackets **NOT** required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, **ALLOW**:  **ALLOW** following geometry throughout:  **TAKE CARE**: structures may be in different orientations. For $H_2NCH_2CH_2NH_2$, **ALLOW**  *(connectivity within 'loop' only)* **If Cl_2s are shown instead of Cl, penalise 1st time only**

	(c)	**(i)**	O_2/oxygen **bonds** to Fe^{2+}/Fe(II) ✓ *Fe^{2+}/Fe(II) essential for 1st marking point* (When required,) O_2 substituted **OR** O_2 released ✓ *Fe^{2+} not required for 2nd marking point (e.g. **IGNORE** Fe)*	**2**	**ASSUME that 'it' refers to oxygen** **ALLOW** O_2 **binds** to Fe^{2+} **OR** O_2 donates electron pair to Fe^{2+} **OR** O_2 is a ligand with Fe^{2+} **IGNORE** O_2 reacts with Fe^{2+} **OR** O_2 is around Fe^{2+} **ALLOW** bond to O_2 breaks when O_2 required **OR** H_2O replaces O_2 **OR** vice versa **ALLOW** CO_2 replaces O_2 **OR** vice versa **ALLOW** O_2 bonds/binds reversibly
	(c)	**(ii)**	$(K_{stab} =) \frac{[HbO_2(aq)]}{[Hb(aq)]\,[O_2(aq)]}$ ✓ **ALL Square brackets essential**	**1**	**ALLOW** expression without state symbols (*given in question*)
	(c)	**(iii)**	**Both marks require a comparison** Stability constant/K_{stab} value with CO is **greater** (than with complex in O_2) ✓ (Coordinate) bond with CO is **stronger** (than O_2) **OR** CO binds more strongly ✓	**2**	**IGNORE** (complex with) CO is more stable **ALLOW** bond with CO is less likely to break (than O_2) **OR** CO is a stronger ligand (than O_2) **OR** CO has greater affinity for ion/metal/haemoglobin (than O_2) **ALLOW** CO bond formation is irreversible **OR** CO is not able to break away **IGNORE** CO bonds more easily **OR** CO complex forms more easily
			Total	**18**	

Question			er	Marks	Guidance
3	(a)		$2Fe + 3Cl_2 \longrightarrow 2FeCl_3$ ✓	1	**ALLOW** $2Fe + 3Cl_2 \longrightarrow Fe_2Cl_6$ **ALLOW** multiples, e.g. $Fe + 1½Cl_2 \longrightarrow FeCl_3$ **IGNORE** state symbols **DO NOT ALLOW** $2Fe + 3Cl_2 \longrightarrow 2Fe^{3+} + 6Cl^-$
	(b)		$Fe^{3+} + 3OH^- \longrightarrow Fe(OH)_3$ ✓	1	**IGNORE** state symbols **ALLOW** $[Fe(H_2O)_6]^{3+} + 3OH^- \longrightarrow Fe(H_2O)_3(OH)_3 + 3H_2O$ **ALLOW** $[Fe(H_2O)_6]^{3+} + 3OH^- \longrightarrow Fe(OH)_3 + 6H_2O$
	(c)	(i)	$2[Fe(H_2O)_6]^{3+} + Zn \longrightarrow 2[Fe(H_2O)_6]^{2+} + Zn^{2+}$ All chemical species correct (**IGNORE** e^- for 1st mark) ✓ Balancing with '2' in front of **both** Fe complex ions ✓	2	**IGNORE** state symbols **For 1 mark,** **ALLOW** balancing if (aq) species have been used instead of complex ions: $2Fe^{3+} + Zn \longrightarrow 2Fe^{2+} + Zn^{2+}$
		(ii)	redox ✓	1	**ALLOW** reduction **AND** oxidation **CARE**: possible confusion with **(d)(ii)**
	(d)	(i)	Formula of **E** as $[Fe(CN)_6]^{3-}$ shown as product in equation ✓ Correct balanced equation: $[Fe(H_2O)_6]^{3+} + 6CN^- \longrightarrow [Fe(CN)_6]^{3-} + 6H_2O$ ✓ Notice different charges on complex ions: LHS 3+, RHS 3– state symbols **not** required	2	**ALLOW** equations with KCN, i.e.: $[Fe(H_2O)_6]^{3+} + 6KCN \rightarrow [Fe(CN)_6]^{3-} + 6K^+ + 6H_2O$ $[Fe(H_2O)_6]^{3+} + 6K^+ + 6CN^- \rightarrow [Fe(CN)_6]^{3-} + 6K^+ + 6H_2O$ **ALLOW** ECF for an equation showing formation of $[Fe(CN)_6]^{4-}$ from $[Fe(H_2O)_6]^{2+}$: $[Fe(H_2O)_6]^{2+} + 6CN^- \longrightarrow [Fe(CN)_6]^{4-} + 6H_2O$ Notice different charges on complex ions: LHS 2+, RHS 4–
		(ii)	ligand substitution ✓	1	**ALLOW** ligand exchange **OR** ligand replacement **CARE**: possible confusion with **(c)(ii)**

Question			er	Marks	Guidance
	(e)		**F** and **G**:  1 mark for each isomer ✓✓ *Bonds **must** go to O ligand atoms on **EACH** structure* ***IGNORE** charges on Fe^{3+} and O^{-} at this stage* 3– charge outside brackets of **BOTH** isomers **AND NO** charges shown on Fe or O within brackets **Note**: This mark is only available from structures with three bidentate ligands bonded to Fe via two Os on each ligand ✓	3	**ALLOW** any attempt to show bidentate ligand Bottom line is the diagram below.  **IGNORE** structure between two Os in ligand even if slightly different Must contain 2 out wedges, 2 in wedges and 2 lines in plane of paper. For bond into paper, **ALLOW**: 
	(f)		FeO_4^{2-} ✓	1	Formula **AND** charge needed **ALLOW** other 2– ions containing: Fe **AND** O **AND** Fe has ox no of +6 i.e. **ALLOW** $Fe_2O_7^{2-}$**,** $Fe_3O_{10}^{2-}$, etc.
			Total	**12**	

Question			er	Marks	Guidance
4	(a)		$(1s^2 2s^2 2p^6)\ 3s^2 3p^6 3d^8 4s^2$ ✓ $(1s^2 2s^2 2p^6)\ 3s^2 3p^6 3d^8$ ✓	2	**ALLOW** 4s before 3d, i.e. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$ **IF** candidate has used subscripts **OR** caps, **DO NOT ALLOW** when first seen but credit subsequently, i.e. $1s_2 2s_2 2p_6 3s_2 3p_6 3d_8 4s_2$ $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3D^8$ For Ni^{2+} **ALLOW** $4s^0$ in electron configuration
	(b)	(i)	Acts as a base **OR** alkali **AND** removes/accepts a proton (from DMGH) ✓	1	
		(ii)	4 ✓	1	
		(iii)	(Each) DMG has 1– charge which **cancel** 2+ charge on Ni^{2+} ✓	1	**ALLOW** 2 x –1 + 2 = 0 For Ni^{2+}, **ALLOW** Ni has an oxidation number of (+)2 **ALLOW** Ni^{2+} cancelled out by 2 DMG^- **ALLOW** 'balanced' for cancelled
		(iv)	 ✓	1	**ALLOW** OH for O—H **ALLOW** CH_3— **DO NOT ALLOW** —H—O

Question			er	Marks	Guidance
	(c)		**Marks are for correctly calculated values** *amount of Ni* ---------- amount $Ni(DMG)_2$ **OR** amount hydrated salt **OR** amount Ni^{2+} $= \frac{2.57}{288.7}$ = **$8.9(0) \times 10^{-3}$** mol ✓ *M values* ---------- *M*(hydrated salt) = $\frac{2.50}{8.90 \times 10^{-3}}$ = **280.9** (g mol^{-1}) ✓ *M*(anhydrous salt) = $\frac{1.38}{8.90 \times 10^{-3}}$ = **155.0** (g mol^{-1}) ✓ *H_2O* ---------- mass H_2O = 2.50 – 1.38 = **1.12 g** ✓ *n*(H_2O) from mass or *M* values = $\frac{1.12}{18.0}$ = **$6.2(2) \times 10^{-2}$** **OR** 280.9 – 155.0 ~**125.9** ✓ waters of crystallisation = $\frac{6.22 \times 10^{-2}}{8.90 \times 10^{-3}}$ = **7** **OR** $\frac{125.9}{18.0}$ = **7** ✓ *Anion* ---------- Molar mass of anion = 280.9 – (58.7 + 7 x 18) = **96.1** (g mol^{-1}) **OR** Molar mass of anion = 155.0 – 58.7 = **96.3** (g mol^{-1}) ✓ *Formula* ---------- Formula of salt is **$NiSO_4 \bullet 7H_2O$** ✓	**7 max**	**ANNOTATE WITH TICKS AND CROSSES, etc** **Note:** The answers incorporate three different approaches to solving this problem. **IF candidate attempts calculation via another method, consult your TL** **ECF** answer above **ALLOW** numerical answers 280.8 – 280.9 (**ALLOW** 281) **IGNORE** further figures **ALLOW** numerical answers 155.0 – 155.1 (**ALLOW** 155) **IGNORE** further figures **ASSUME** that 'unlabelled 1.12 g' applies to H_2O unless contradicted **ALLOW** numerical answers 125.7 – 125.9 (**ALLOW** 126) **ECF** answer above **7** as whole number is required **Note:** Mark for 7 can be credited within formula **BUT** there must be some relevant working to derive ~7, e.g. 6.99 **ALLOW** numerical answers 96.0 – 96.4 (**ALLOW** 96)
			Total	**13**	