Questions

Q1.

Ammonium cobalt(II) sulfate is made by mixing aqueous solutions of ammonium sulfate and excess cobalt(II) sulfate.

Dry crystals of ammonium cobalt(II) sulfate, $(NH_4)2SO_4 \cdot CoSO_4 \cdot 6H_2O$, are obtained by the procedure shown.

Step **1** The reaction mixture is transferred to an evaporating basin, heated gently and then left to crystallise.

Step **2** The crystals are separated by gravity filtration.

Step **3** The crystals are then **rinsed** with a small amount of **ice-cold** water.

Step **4** The rinsed crystals are placed in a **warm oven** for 30 minutes.

(i) The colour of the cobalt(II) sulfate solution used is pink due to the complex cobalt(II) ion, $[Co(H_2O)_6]^{2+}$.

Explain why the solution is coloured.

(4)

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(ii) Explain the shape of the cobalt(II) ion, $[Co(H_2O)_6]^{2+}$, using electron-pair repulsion theory.

(3)

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(iii) Give the reasons for carrying out Steps **3** and **4** of the procedure, referring particularly to the words in bold.

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(Total for question = 10 marks)

Q2.

Ammonium cobalt(II) sulfate is made by mixing aqueous solutions of ammonium sulfate and excess cobalt(II) sulfate.

Dry crystals of ammonium cobalt(II) sulfate, $(NH_4)2SO_4 \cdot CoSO_4 \cdot 6H_2O$, are obtained by the procedure shown.

Step **1** The reaction mixture is transferred to an evaporating basin, heated gently and then left to crystallise.

Step **2** The crystals are separated by gravity filtration.

Step **3** The crystals are then **rinsed** with a small amount of **ice-cold** water.

Step **4** The rinsed crystals are placed in a **warm oven** for 30 minutes.

The percentage yield of this reaction is 70.0%.

Give **two** possible reasons, other than an incomplete reaction, why the yield is less than 100%.

(2)

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(Total for question = 2 marks)

Q3.

This question is about transition metal chemistry.

Dilute aqueous ammonia is added, drop by drop, to an aqueous solution of copper(II) sulfate until the aqueous ammonia is in excess.

(i) Describe what you would **see** during this experiment.

(2)

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(ii) The reaction between aqueous copper(II) sulfate and **excess** aqueous ammonia is an example of a **ligand substitution** reaction.

Write an equation for the ligand substitution reaction that occurs, showing the formulae of the complex ions involved. State symbols are not required.

(2)

(Total for question = 4 marks)

Q4.

This is a question about catalysis.

The reaction between iodide ions and peroxodisulfate ions is catalysed by iron(II) ions.

$$2I^- + S_2O_8^{2-} \xrightarrow{Fe^{2+}} I_2 + 2SO_4^{2-}$$

(i) Give a reason why the reaction between iodide ions and peroxodisulfate ions has a high activation energy and is therefore very slow without a catalyst.

(1)

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(ii) Explain, with the aid of two equations, how the iron(II) ions catalyse this reaction. State symbols are not required.

(3)

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(Total for question = 4 marks)

Q5.

A student stated that 'the elements scandium and zinc are d-block elements but are not transition metals'.

Discuss this statement, using appropriate electronic configurations to support your answer.

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(Total for question = 4 marks)

Q6.

This question is about transition metals and transition metal complexes.

When chromium(III) sulfate dissolves in water, a green solution containing the $[Cr(H_2O)_6]^{3+}$ ion forms.

(i) Give the shape of this complex ion.

(1)

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(ii) Explain why the chromium complex ion is coloured.

(3)

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(Total for question = 4 marks)

Q7.

This is a question about chromium(III) and chromium(VI) compounds.

Describe the observations when aqueous sodium hydroxide is added drop by drop until in excess to a solution of chromium(III) ions.

(2)

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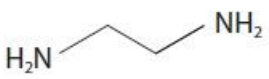
(Total for question = 2 marks)

Q8.

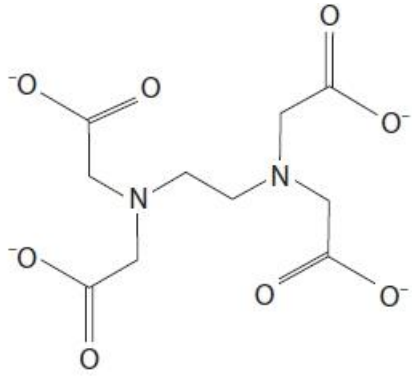
Transition metals form complex ions.

Compare and contrast the complex ions formed by cobalt(III) ions with the ligand ethane-1,2-diamine and with the ligand $EDTA^{4-}$.

Ignore any difference in colour.



ethane-1,2-diamine



$EDTA^{4-}$

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(Total for question = 4 marks)

Q9.

*"Cobalt(II) ions combine with substances in solution to form complex ions with different coordination numbers."

Discuss this statement by referring to **two** complex ions containing cobalt(II).

Include

- reference to any difference in colour
- a definition of any terms used
- an explanation of the different shapes

(Total for question = 6 marks)

Q10.

Iron and zinc are in the d-block of the Periodic Table.

Hydrated iron(II) ions react with ethanedioate ions, $C_2O_4^{2-}$, to form a complex ion.

$$[Fe(H_2O)_6]^{2+} + 2C_2O_4^{2-} \rightleftharpoons [Fe(C_2O_4)_2(H_2O)_2]^{2-} + 4H_2O$$

(i) Draw a structure of the $[Fe(C_2O_4)_2(H_2O)_2]^{2-}$ ion, showing **all** of the bonds.

(2)

(ii) Explain, in terms of entropy, why this reaction is feasible.

(2)

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(Total for question = 4 marks)

Q11.

This question is about the chemistry of elements in the *d*-block of the Periodic Table.

* Many of the *d*-block elements are also classified as transition metals.

Explain why two of the *d*-block elements within Period 4 (scandium to zinc) are **not** classified as transition metals.

You should include **full** electronic configurations where relevant.

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(Total for question = 6 marks)

Q12.

Iron and zinc are in the d-block of the Periodic Table.

Iron(II) ions, $[Fe(H_2O)_6]^{2+}$, form a pale green solution but zinc ions, $[Zn(H_2O)_6]^{2+}$, form a colourless solution.

Explain why zinc ions are colourless.

(2)

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(Total for question = 2 marks)

Q13.

This question is about transition metals and their ions.

The complex ions of transition metals have different colours in aqueous solution.

Two factors that affect the colour of the solution are the oxidation number of the central metal ion, and the ligands present.

Give examples to illustrate these factors by referring to complex ions of iron and/or copper. Include the formula and colour of each complex.

An explanation of why transition metal ions are coloured is **not** required.

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(Total for question = 3 marks)

Q14.

Transition metals form complex ions.

Complex ions have a central metal ion surrounded by ligands.

(i) Give a reason why the ammonium ion cannot act as a ligand.

(1)

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(ii) Explain why the complex ions $[Co(NH_3)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$ are coloured and have different colours.

(4)

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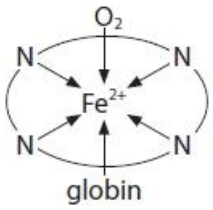
(Total for question = 5 marks)

Q15.

Some organic compounds contain metals.

Haemoglobin is an iron(II) complex. It carries oxygen around the body.
Part of the structure of haemoglobin is shown.



The four nitrogen atoms are part of a multidentate ligand in the haem group.

Explain why inhaling carbon monoxide can be fatal.

(2)

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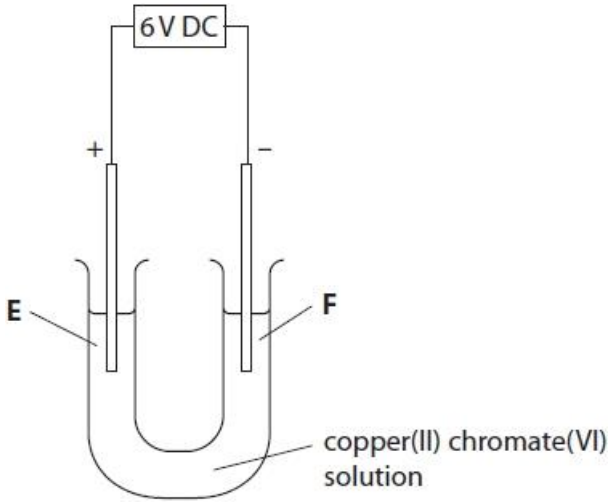
(Total for question = 2 marks)

Q16.

This question is about structure and bonding.

An aqueous solution of copper(II) chromate(VI) was electrolysed using the apparatus shown in the diagram.



Deduce the colours of the solutions in regions **E** and **F** after the electrolysis has occurred.

(2)

Colour in region **E** .....

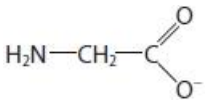
Colour in region **F** .....

(Total for question = 2 marks)

Q17.

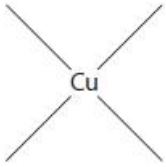
This question is about transition metals.

Glycinate ions are bidentate ligands and can be represented by the structure



Complete the diagram below to show the structure of the $[Cu(NH_2CH_2COO)_2]$ complex, which is square planar.

(2)

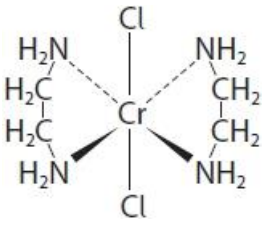


(Total for question = 2 marks)

Q18.

This question is about transition metals and their ions.

The **shape** of a complex ion formed from Cr^{3+} ions is shown.



(i) State the coordination number of Cr^{3+} in this complex ion.

(1)

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(ii) State the overall charge on this complex ion.

(1)

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(Total for question = 2 marks)

Q19.

Colour is often used in chemistry to identify substances.

Compare and contrast the origin of the colour of a copper(II) complex with the origin of the colour of the copper(II) ion in a flame test.

You do not need to state any specific colours.

(6)

(Total for question = 6 marks)

Mark Scheme

Q1.

Question Number	Answer	Additional Guidance	Mark
(i)	An explanation that makes reference to the following points: **Splitting** • (ligand / water molecule causes) d orbitals to split (into 2 energy levels) **(1)** **Absorption** • electrons absorb energy (in the visible region) / photons (of visible light) **(1)** **Promotion** • to promote electrons (to higher d orbitals) **or** electrons move from lower to higher energy (d) orbitals / levels **(1)** **Colour** • the remaining light / unabsorbed light / complementary colour / pink light is transmitted **(1)**	Penalise omission of 'd' once only Allow d subshell / shell for d orbitals Do not award 'a d orbital is split' Do not award 'electrons are split' Allow energy / photons / light absorbed Allow d-d transitions occur Allow electrons are excited / jump for promote Ignore reference to electron(s) relaxing / dropping to ground state Do not award d-s transitions Allow reflected / emerged / seen Do not award 'emitted'	**(4)**

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: **Electron pairs** • 6 (dative) pairs of (bonding) electrons (around cobalt ion) **(1)** **Minimise repulsion** • (electron / bond pairs) arranged in order to minimise repulsion **(1)** **Shape** • so shape is octahedral **(1)**	Pairs only needs to be mentioned once in M1 or M2 Allow areas of electron density for pairs of electrons Allow 6 bond(ing) pairs May be shown on diagram but dative bonds must be between O and Co^{2+} Do not award mention of having any lone pairs Allow to maximise separation between electron / bond pairs or the electron / bond pairs are as far apart as possible Ignore equal repulsion between bond pairs Ignore comments based on repulsion / separation between bonds / atoms Ignore comments on repulsion between bond pairs and lone pairs Allow 3-D diagram to show octahedral shape Allow square based **bi**pyramidal Do not award octagonal No TE on incorrect number of electron pairs Ignore bond angles	**(3)**

Question Number	Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to the following points: **Rinsed** • rinsed to remove cobalt(II) sulfate (solution) **(1)** **Ice-cold water** • ice-cold water minimises / prevents ammonium cobalt(II) sulfate / crystals (re)dissolving **(1)** **Warm oven** • warm oven (rather than hot) to ensure water of crystallisation is not removed (during drying) **or** to stop the crystals melting **(1)**	Allow to remove remaining solution Allow to remove impurities that didn't crystallise Allow just 'to remove impurities' Ignore to remove ammonium sulfate Ignore to remove solvent Do not award to remove insoluble impurities Allow the crystals are insoluble / less soluble in cold water Ignore to stop the reaction Do not award to stop the crystals melting Allow to dry crystals / remove water Do not award to remove water of crystallisation / heat to constant mass	(3)

Q2.

Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to **two** of the following points: • some ammonium cobalt(II) sulfate solution lost if it 'spits' out of basin when heated (in Step 1) **(1)** • some ammonium cobalt(II) sulfate remains in solution (in Step 1) **(1)** • some ammonium cobalt(II) sulfate is soaked into the filter paper/ some ammonium cobalt(II) sulfate crystals remain on filter paper (in Step 2) **(1)** • transfer losses from reaction flask / beaker to evaporating basin / from evaporating basin to filter funnel (in Steps 1 and 2) **(1)** • some water of crystallisation is lost during the drying process (in Step 4) **(1)**	Allow e.g. crystals / salt / solid / product for ammonium cobalt(II) sulfate Do not award crystals evaporated for M1 only Allow the crystals weren't left to crystallise for long enough Allow just 'solid is lost during filtration' Allow any type of specific transfer loss e.g. some product left behind in the beaker / flask / evaporating basin Allow crystals decompose during drying Allow some ammonium cobalt(II) sulfate dissolves in ice-cold water (in Step 3) Ignore formation of alternative product Ignore reaction is reversible	**(2)**

Q3.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	A description that makes reference to the following points: • (blue solution initially forms pale) blue precipitate **(1)** • (which dissolves to) form dark/deep/royal blue solution **(1)**	Allow 'solid' / 'ppt' for 'precipitate' Do not award for 'blue crystals' Do not allow dark blue ppt	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$ • LHS of equation correct **(1)** • RHS of equation correct **(1)**	Ignore state symbols even if incorrect Ignore balanced sulfate ions Do not award just Cu^{2+} on LHS Allow $[Cu(OH)_2(H_2O)_4] + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2H_2O + 2OH^-$ Do not award for $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_6]^{2+}$ on RHS	**(2)**

Q4.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following point: • the two negative ions repel each other	Reference to both charge and repulsion needed	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • equation with oxidation of iron(II) ions **(1)** • equation with reduction of iron(III) ions **(1)** • (catalysis is possible because) variable oxidation state/iron has more than one oxidation state/number **or** both steps now involve oppositely charged ions **(1)**	Example of equations $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ Allow multiples Ignore state symbols even if incorrect Allow one mark if the two correct equation are given in the wrong order Allow reference to iron being oxidised and reduced Allow reference to the iron ions being positive and so not repelled	**(3)**

Q5.

Question Number	Answer	Additional guidance	Mark
	A discussion that makes reference to the following points: • both elements / atoms have the last added electron in the d-subshell / d orbital (so are d-block elements) **(1)** • but neither forms a (stable) ion with an incomplete d-subshell / d orbital (so are not transition metals) **(1)** • Zn^{2+} is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ (so d subshell is full) **(1)** • Sc^{3+} is $1s^2 2s^2 2p^6 3s^2 3p^6$ (so d subshell is empty) **(1)**	Do not award just 'contains d electrons' Allow 'transition elements form a (stable) ion with an incomplete d-subshell / d orbital' Allow $[Ar]3d^{10}$ Allow [Ar]	**(4)**

Q6.

Question Number	Answer	Additional Guidance	Mark
(i)	• octahedral	Allow octahedron / octahedral Ignore diagrams Do not award octagonal	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points • (ligand / water molecule causes) d orbitals to split (into 2 energy levels) **(1)** • light/energy (in the visible region) absorbed to promote electrons (to higher d orbitals) **(1)** • the remaining light / unabsorbed light / complementary colour / green light is transmitted **(1)**	Allow d subshell for d orbitals Do not award d orbital splits Allow (some light) energy is absorbed when d-d electron transitions occur Do not award 'emitted' or transmission linked to electrons returning to ground state Allow reflected / emerged	(3)

Q7.

Question Number	Answer	Additional Guidance	Mark
	A description that makes reference to • green ppt. **(1)** • ppt dissolves (in excess NaOH) to give a green solution **(1)**	Accept 'green solid' Allow 'grey-green ppt Do not award blue-green Ignore shades M2 dependent upon M1 or near-miss	(2)

Q8.

Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to (Similarities) At least one from • both ligands form dative covalent bonds with the cobalt(III) ions (1) • both have coordination number 6 (1) • both complex ions will be octahedral (1) (Differences) At least one from • EDTA is hexadentate, ethane-1,2-diamine is bidentate OR ratio of cobalt(III) to EDTA is 1:1, with ethane-1,2-diamine it is 1:3 (1) • complex with EDTA will be anionic / negatively charged, with ethane-1,2-diamine will be cationic / positively charged (1) • complex of EDTA is more stable than the complex with ethane-1,2-diamine because there is an increase in entropy (1)	There must be some comparison. Hence two separate paragraphs on each complex without this scores max (3) Allow both donate lone pairs of electrons to cobalt(III) ions Allow both have 6 coordinate bonds Accept EDTA forms 6 bonds and ethane-1,2diamine forms 2 Ignore multidentate/polydentate ALLOW EDTA is an anion, ethane-1,2-diamine is neutral Allow molar ratios to illustrate, even if incorrect	(4)

Q9.

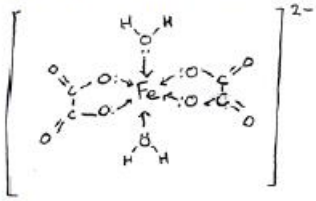
Answer	Additional Guidance
This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. Number of indicative marking points seen in answer / Number of marks awarded for indicative marking points 6 / 4 5-4 / 3 3-2 / 2 1 / 1 0 / 0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield and overall score of 3 marks (3 marks for indicative content and zero marks for linkages). Penalise incorrect chemistry such as bond angles of 90° for tetrahedral complexes or incorrect oxidation number by deducting a reasoning mark

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure of answer and sustained lines of reasoning
Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content	Accept any six indicative content points More than one indicative marking point may be made within the same comment or explanation
• **IP1** formulae and colour of first complex ion	$[Co(H_2O)_6]^{2+}$ allow $[Co(NH_3)_6]^{2+}$ or $[Co(EDTA)]^{2-}$ or $[Co(en)_3]^{2+}$ **and** pink or yellow/brown for the hexaamine complex
• **IP2** formulae and colour of second complex ion	$[CoCl_4]^{2-}$ allow $[Co(OH)_4]^{2-}$ **and** blue
• **IP3** definition of ligand	Atom/ion/molecule/species dative covalently bonded/ coordinately bonded to a central metal ion which can be shown on a diagram
• **IP4** definition of and example(s) of coordination number	The number of dative covalent bonds (to a central metal ion) **and** Six and/or four respectively which may be in a diagram
• **IP5** shape of complex ion(s)	Octahedral and/or tetrahedral respectively and can be a diagram. If two given then both must be correct
• **IP6** the chloride ion is larger (than the oxygen in water ligand or nitrogen in the ammonia ligand)	Allow chloride ions are large and only fit four around the metal ion Do not award 'molecule' when referring to chlorine Accept reverse argument

Q10.

Question Number	Answer	Additional Guidance	Mark
(i)	• 2 water ligands joined between O and Fe **(1)** • 2 ethanedioate ligands drawn correctly showing all the bonds **and** joined between single-bonded O atoms and Fe as shown **(1)**	Example of structure  Allow water ligands arranged as *cis* or *trans* Allow delocalised bonds in ethanedioate ions Allow bonds not shown in H_2O, provided the ligands are attached to Fe^{2+} through oxygen atoms Ignore bond lengths and angles Ignore wedges and dotted lines to show shape Ignore missing lone pairs and arrowheads Ignore missing square brackets and charge / incorrect charge Ignore –ve charges on ethanedioate ions / +ve charge on Fe	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • (there are) more particles / moles / species on the right of the equation (than on the left) **or** (there is an increase from) 3 particles on the left of the equation to 5 on the right **(1)** • so ΔS_{system} increases / is positive (and $\Delta S_{surroundings}$ is unchanged so ΔS_{total} increases) **(1)**	Do not allow incorrect numbers of particles Do not allow 3 molecules on the left and 5 molecules on the right Allow ΔS_{total} is positive / increasing Allow entropy / ΔS increases Allow there is a positive entropy change Ignore just there is an increase in disorder (from left to right) Ignore $\Delta S_{surroundings}$ changes Ignore just 'entropy is positive' Ignore references to free energy	(2)

Q11.

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*</td>
<td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>

The following table shows how the marks should be awarded for structure and lines of reasoning.</td>
<td>Guidance on how the mark scheme should be applied:
The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).
If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

In general it would be expected that 5 or 6 indicative points would score 2 reasoning marks, and 3 or 4 indicative points would score 1 reasoning mark. A total of 2, 1 or 0 indicative points would score 0 marks for reasoning.

Reasoning marks may be subtracted for extra incorrect chemistry.</td>
<td>(6)</td>
</tr>
</table>

		Number of marks awarded for structure of answer and sustained line of reasoning		
	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.	2		
	Answer is partially structured with some linkages and lines of reasoning.	1		
	Answer has no linkages between points and is unstructured.	0		

	Indicative content (IPs) **IP1:** • (transition metal) forms an **ion** with an incomplete *d* sub-shell	Allow 'partially-filled' for incomplete Allow *d*-orbital(s) Do not award "*d*-shell" Allow "*D*" for "*d*" throughout	
	IP2: • scandium **and** zinc are not transition metals	Allow if **only** Sc **and** Zn are used to illustrate *d*-block elements that are not transition metals	
	IP3: • Sc^{3+} **and** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$	Allow $4s^0$ and/or $3d^0$ Penalise use of [Ar] once only	
	IP4: • Zn^{2+} **and** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$		
	IP5: • Sc^{3+} **and** *d* sub-shell empty / *d*-orbitals empty	Allow "Sc^{3+} has no *d* sub-shell"	
	IP6: • Zn^{2+} **and** *d* sub-shell full / **ALL** *d*-orbitals are full	Allow 'd orbital is full' if clarified by $3d^{10}$	

Q12.

Question Number	Answer	Additional Guidance	Mark
	An explanation that makes reference to the following points: • (zinc (ions) / Zn^{2+}) has / have a full (3)d sub-shell / $3d^{10}$ / all (3)d orbitals are full **(1)** • so d-d transitions cannot take place **or** electrons cannot move between (3)d orbitals **or** electrons cannot be promoted / excited to higher (3)d orbitals **(1)**	Allow zinc (ions) / Zn^{2+} do not have a partially filled / incomplete (3)d (sub-) shell / no empty (3)d orbitals Do not allow zinc atoms Ignore omission of 'd' in the 'or's, if it is included in M1 Do not allow the (3)d orbitals do not split / the (3)d subshell does not split Ignore just 'movement to different energy level'	**(2)**

Q13.

Question Number	Acceptable Answers	Additional Guidance	Mark
		Ignore ions of metals other than iron or copper Ignore use of precipitates instead of complex ions Ignore names of complex ions, even if incorrect Penalise additional incorrect species / colours once only	**(3)**
	Oxidation state: • Two ions of the **same metal** (iron or copper) with different oxidation states and the same ligands with appropriate colours **(1)**	<u>Examples of ions</u> $[Fe(H_2O)_6]^{2+}$ is green **and** $[Fe(H_2O)_6]^{3+}$ is yellow / orange / red/ brown $[CuCl_4]^{2-}$ is yellow **and** $[CuCl_2]^-$ is colourless	
	Ligands: • formula and colour of complex with first ligand **(1)** • formula and colour of complex with second ligand **(1)**	$[Cu(H_2O)_6]^{2+}$ is (pale) blue **and** $[CuCl_4]^{2-}$ is yellow $[Cu(H_2O)_6]^{2+}$ is (pale) blue **and** $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_4(H_2O)_2]^{2+}$ / $[Cu(H_2O)_2(NH_3)_4]^{2+}$ is a **darker** blue than in the aqua ion $[CuCl_4]^{2-}$ is yellow and $[Cu(NH_3)_4]^{2+}$ / $[Cu(NH_3)_4(H_2O)_2]^{2+}$ / $[Cu(H_2O)_2(NH_3)_4]^{2+}$ is (deep / dark) blue	

		Allow any correct example of the **same metal** in the same oxidation state with different ligands and their corresponding colours, including colourless – the metal can be different to that in M1 **Note** Formulae **and** colours must be correct but ignore missing square brackets e.g. Do not award mention of green for $[CuCl_4]^{2-}$ Do not award $[Cu(NH_3)_6]^{2+}$ Ignore qualifications of colour e.g. pale / dirty	

Q14.

Question Number	Answer	Additional Guidance	Mark
(i)	• ammonium ions do not have a lone pair (of electrons for bonding)	Allow ammonium ions are positive and so are repelled (by the positive metal cation) Ignore reference to it already having a dative/coordinate bond	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to • d orbitals/d sub-shell split (into two different energies) (1) • difference in energy depends on the ligands (1) • difference in energy leads in different frequencies/wavelengths/photons of light absorbed (1) • (so) the unabsorbed frequencies/wavelengths/photons are reflected/transmitted (1)	 Ignore 'distort' Do not award splitting of singular d orbital Allow 'colour seen' for reflected/transmitted Do not award 'emission' Do not award M3 nor M4 if reference to electron 'falling' releases energy is stated	(4)

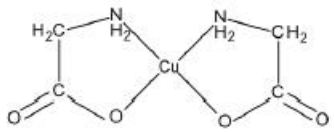
Q15.

Question Number	Acceptable Answers	Additional Guidance	Mark
	An explanation that makes reference to any **TWO** of the following points:		**(2)**
	• carbon monoxide replaces / takes the place of the oxygen molecule **(1)**	Allow carbon monoxide displaces the oxygen molecule Allow ligand substitution / exchange reaction between oxygen and carbon monoxide	
	• (and may be toxic because) it binds strongly to the Fe^{2+} (ion) **(1)**	Allow carbon monoxide forms a stronger bond / binds more tightly to / has a stronger affinity for Fe^{2+} Allow reduces the amount of oxygen that can bind to Fe^{2+} Allow carbon monoxide binds (almost) irreversibly / permanently to Fe^{2+} Allow CO forms a more stable complex ion with Fe^{2+} / has a larger equilibrium constant / K Ignore CO bonds more easily to Fe^{2+} Ignore just 'CO bonds more strongly to haemoglobin'	
	• effect on the body **(1)**	Allow prevents oxygen being carried to the cells / organs / around the body / blood Allow reduces the amount of oxygen that can be carried to the cells / organs / around the body / blood	

Q16.

Question Number	Answer	Additional Guidance	Mark
	• region **E**: yellow **(1)**	Ignore additional descriptions of colours e.g. pale, bright	**(2)**
	• region **F**: blue **(1)**	Do not award any other colours e.g. blue-green	

Q17.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• **2** glycinate ligands attached to Cu through nitrogen atoms **(1)** • **2** glycinate ligands attached to Cu through single bonded oxygen atoms **and** rest of structure correct **(1)**	Example of structure  Allow the two ligands attached to any 2 pairs of adjacent bonds Allow *cis* or *trans* isomer / delocalised carboxylate groups / skeletal formulae Ignore bond lengths and bond angles Ignore lone pairs of electrons, charge on the copper or oxygen ions and direction of dative covalent bonds Do not award M1 if bond between Cu and H of NH_2	**(2)**

Q18.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• six / 6		**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	• 1+ / +1	Allow + / one positive charge Ignore positive / plus	**(1)**

Q19.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained lines of reasoning</th></tr>
<tr><td>Answer shows a coherent logical structure with linkages
and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table></td><td>Guidance on how the mark scheme should be applied:
The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).
If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and zero marks for linkages).

If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).

More than one indicative marking point may be made within the same comment or explanation

Deduct a reasoning mark if no comparison made

Penalise the use of 'atom' instead of ion once only against any indicative point</td><td>(6)</td></tr>
</table>

	Indicative content Similarities • **(IP1)** the differences in energy levels determines the colour of the flame test and complex ion Differences Flame test • **(IP2) heat** (energy) results in electron promotion • **(IP3)** return of an (excited) electron to a lower (energy) state Complex ion • **(IP4)** d orbitals are split (in energy by the ligands) • **(IP5) light** (energy) is needed for electron promotion • **(IP6)** the colour not absorbed is the colour seen	Ignore incorrect colours This can be mentioned separately or as a comparison Allow electrons excited by **heat** Allow electron is 'de-excited' to a lower (energy) state Do not award if d-d transitions stated Allow d subshell splitting Do not award singular "d orbital" splitting Accept "The colour seen is complimentary to that absorbed" Allow 'colour reflected is the colour seen' Do not award if colour attributed to 'fall' of electron to lower energy d orbital Do not award 'emission of light'	