1(a). This question is about chemicals used by gardeners.

A garden product contains hydrated ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$.

$(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$ contains 27.55% by mass of water of crystallisation.

Calculate the value of x in the formula $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$.

Show your working.

x = ... **[3]**

(b). The garden product in the previous question part is a solid mixture of the following ingredients:

- Hydrated ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$, which is soluble in water
- Crushed limestone (calcium carbonate)
- Sand.

i. Suggest why crushed limestone has been included in this garden product.

_____

[1]

ii. Plan a procedure on a test tube scale to show that the solid mixture contains the following ions:

- NH_4^+, Fe^{2+} and SO_4^{2-} present in $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$
- CO_3^{2-} present in crushed limestone.

Show your reasoning, including relevant equations.

[6]

2. Four pairs of solutions are mixed.

Which pair of solutions forms a white precipitate?

A NH_4Cl (aq) and NaOH(aq)

B KBr(aq) and $AgNO_3$(aq)

C $FeCl_3$(aq) and NH_3(aq)

D $Cr_2(SO_4)_3$(aq) and $BaCl_2$(aq)

Your answer ☐ **[1]**

3. A hydrated nickel(II) complex, **A**, is heated in a crucible to remove the water of crystallisation. The anhydrous complex **B** is formed. The results are shown below.

Mass of crucible + hydrated complex **A**	= 59.554 g
Mass of crucible + anhydrous complex **B**	= 58.690 g
Mass of crucible	= 51.257 g

The anhydrous complex **B** is analysed and found to have a molar mass of 309.7 g mol^{-1} and to contain the following percentage composition by mass:

Ni, 18.95%; C, 23.25%; N, 27.12%; H, 7.75%; C*l*, 22.93%.

The anhydrous complex **B** contains a cation **C** comprising Ni, C, N and H only.
Cation **C** is six-coordinate, contains three molecules of the bidentate ligand **D**, and exists as optical isomers.
Determine the formula of **A**, **B**, **C** and **D** and show the 3D structures for the optical isomers of **C**.
Show **all** your working.

[6]

4. Students work together in groups to identify four different solutions.

Each solution contains one of the following compounds:

- ammonium sulfate, $(NH_4)_2SO_4$
- sodium sulfate, Na_2SO_4
- sodium chloride, NaCl
- potassium bromide, KBr.

Your group has been provided with universal indicator paper and the following test reagents:

- barium chloride solution
- silver nitrate solution
- dilute ammonia solution
- sodium hydroxide solution.

A student in your group suggests the following plan:

- Add about 1 cm depth of each solution into separate test-tubes.
- Add a few drops of barium chloride solution to each test-tube.
- A white precipitate will show which solutions contain sulfate ions.
- Two of the solutions will form a white precipitate.

Describe how you would expand this plan so that all four solutions could be identified using a positive result.

You should provide observations and conclusions that would enable your group to identify all four solutions.

[6]

5. $NH_4Fe(SO_4)_2 \cdot 12H_2O$ is a hydrated 'double salt'.

A student analyses this double salt using test tube tests.

Which row(s) gives/give correct result(s) for the stated test?

	Test	Results
1	Reaction with cold NaOH(aq)	Green precipitate
2	Reaction with $Ba(NO_3)_2$(aq)	White precipitate
3	Reaction with warm NaOH(aq)	Red-brown precipitate and an alkaline gas

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

6. Tutton's salts are 'double salts' with the formula $\mathbf{X}_2\ \mathbf{Y}(\mathbf{Z}O_4)_2 \bullet 6H_2O$.

A Tutton's salt contains two cations: $\mathbf{X}^+$ and $\mathbf{Y}^{2+}$.

- $\mathbf{X}^+$ can be an ion of the Group 1 elements K, Rb, Cs or Fr, or an ammonium ion.
- $\mathbf{Y}^{2+}$ can be a 2+ ion of magnesium or an ion of most of the transition elements in Period 4.
- **Z** can be S or Cr.

$(NH_4)_2Cu(SO_4)_2 \bullet 6H_2O$ is an example of a Tutton's salt.

The student dissolves their Tutton's salt in water. A pale blue solution forms.

The student carries out two tests on this aqueous solution.

i. The student adds an excess of aqueous ammonia to their aqueous solution of Tutton's salt. A deep blue solution forms.

The complex ion responsible for the deep blue solution has a molar mass of 167.5 g mol^{-1}.

Suggest the formula of this complex ion.

[1]

ii. The student adds NaOH(aq) to the aqueous solution of Tutton's salt and warms the mixture.

A precipitate and a gas are formed.

Write the formulae of the precipitate and gas and suggest a test that could confirm the identity of the gas.

Formula of precipitate

Formula of gas

Test to confirm the identity of the gas

[3]

iii. How could the student carry out a test-tube test to confirm the anion in the Tutton's salt?

[2]

7. A student analyses a solution of a salt.

The results are shown below.

Test	**Observation**
Reaction with NaOH(aq)	Green precipitate
Reaction with $Ba(NO_3)_2(aq)$	White precipitate

What is the formula of the salt?

A $CuCl_2$

B $CuSO_4$

C $FeCl_2$

D $FeSO_4$

Your answer

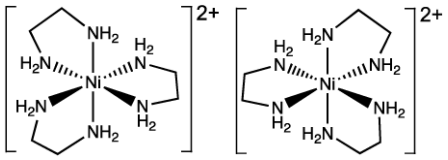
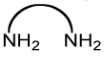
[1]

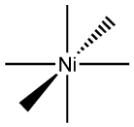
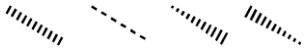
END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		$n(H_2O)$ = 27.55/18.0 = 1.5306 (mol) ✓ $n((NH_4)_2Fe(SO_4)_2)$ = 72.45/284.0 = 0.2551 (mol) ✓ whole number ratio of $(NH_4)_2Fe(SO_4)2 : H_2O$ = 0.2551 : 1.5306 = 1 : 6 **OR** x = 6 ✓	3	**If there is an alternative answer, check to see if there is any ECF credit possible** **ALLOW** calculator value or rounding to two significant figures or more but **IGNORE** 'trailing zeroes' if wrong *M* produces such numbers throughout. **ALLOW ECF** If no working, **ALLOW** 1 mark for *x* = 6.
	b	i	To neutralise acidic soil ✓	1	
		ii	*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Describes practical details of tests and observations that allows all four ions to be identified **AND** Attempts associated equations, with most correct. *There is a well-developed line of reasoning and the method is clear and logically structured. The information presented is relevant and substantiated by observations from the tests described and practical details.* **Level 2 (3–4 marks)** Describes most practical details of tests including the observations that allows most ions to be identified **AND** Attempts associated equations, with some correct.	6	**Indicative scientific points may include** **Practical details:** • Sample stirred with water and mixture filtered. • SO_4^{2-}, Fe^{2+}, NH_4^+ tests on filtrate. • CO_3^{2-} test on residue or garden product **Tests and associated equations:** CO_3^{2-} test: *Test:* Add nitric acid. *Observation:* effervescence. *Equation:* $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$ ***ALLOW*** $CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$ ***OR*** overall equation of $CaCO_3$ and an acid. SO_4^{2-}test: Add $BaCl_2(aq)/Ba(NO_3)_2(aq)/Ba^{2+}(aq)$. Observation: white precipitate. Equation: $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$

			There is a line of reasoning presented and the method has some structure. The information presented is in the most-part relevant and supported by some evidence of observations from the tests described but practical details may be absent. **Level 1 (1–2 marks)** Describes some of the practical details of tests and observations would only allow some ions to be identified. **OR** Attempts associated equations, with some correct. *The information is basic and the method lacks structure. The information is supported by limited evidence of the observations, the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		Fe^{2+} test: Test: Add NaOH(aq) Observation: green precipitate Equation: $Fe^{2+} + 2OH_- \rightarrow Fe(OH)_2$ NH_4^+ test: *Test:* Add NaOH(aq) and warm *Observation:* gas turns red litmus indicator blue *Equation:* $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$
			Total	**10**	
2			**D**	1	
			Total	**1**	
3			*Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** A comprehensive conclusion using all data to obtain correct formulae for **A**, **B**, **C** and **D** **AND** optical isomers shown *There is a well-developed line of reasoning which is clear and logically structured with use of 3D structures for both optical isomers of **C**, use of wedges and bonding to N. The information presented is*	6	**Indicative scientific points may include:** **1. Formula of anhydrous complex B** $NiC_6N_6H_{24}Cl_2$ *Example of working* $\frac{Ni}{18.95} : \frac{C}{23.25} : \frac{N}{27.12} : \frac{H}{7.75} : \frac{Cl}{22.93}$ $= \frac{18.95}{58.7} : \frac{23.25}{12.0} : \frac{27.12}{14.0} : \frac{7.75}{1.00} : \frac{22.93}{35.5}$ ***There may be other methods*** **2. Formula of hydrated complex A** $NiC_6N_6H_{24}Cl_2 \cdot 2H_2O$ **OR** $NiC_6N_6H_{24}Cl_2(H_2O)_2$

			relevant and substantiated. **Level 2 (3–4 marks)** Reaches a sound conclusion for the formula of **B** **AND** obtains the correct formula of the hydrated complex **A** **OR** a 3D diagram of one optical isomer of cation **C** *There is a line of reasoning and supported by some evidence. Calculations are clear and can be followed to obtain correct conclusions. 3D diagram, if present, should use wedges mostly correctly. Formula of **A** to show water separately or formula of **C** to show ligands separately, as appropriate.* **Level 1 (1–2 marks)** Reaches a simple conclusion to obtain the correct formula of anhydrous complex **B OR** shows that **A** contains $2H_2O$ *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. Attempts more than one part of the problem.* **0 marks** *No response or no response worthy of credit.*		*Example of working* $n(\text{anhydrous salt}) = \frac{7.433}{309.7} = 0.02400\ (\text{mol})$ $n(H_2O) = \frac{0.864}{18.0} = 0.04800\ (\text{mol})$ ✓ ***There may be other methods*** **3. Formula of cation C** $[NiC_6N_6H_{24}]^{2+}$ **OR** $[Ni(H_2NCH_2CH_2NH_2)_3)]^{2+}$ *(could be in structures* 2+ charge can be shown on cation **OR** optical isomers (i.e. seen somewhere) • **Bidentate ligand D** $H_2NCH_2CH_2NH_2$ or displayed so that structure is clearly unambiguous. • **Optical isomers**  *Accuracy of structures* Bonding shown from Ni to N of $H_2NCH_2CH_2NH_2$ **ALLOW** $CH_3CH(NH_2)_2$ for ligand For $H_2NCH_2CH_2NH_2$ in optical isomers, **ALLOW** C–C without Hs and  Each structure to contain 2 'out wedges', 2 'in wedges' and 2

					lines in plane of paper **OR** 4 lines, 1 'out wedge' and 1 'in wedge':  Bond into paper can be shown as:  **Examiner's Comments** This was the second extended response question. Most candidates were able to make a start on this response and found the formula of **B.** A significant number of candidates assumed the bidentate ligand **D** to be $H_2NCH_2CH_2NH_2$ and worked backwards to identify **C.** Having identified **C**, the drawing of optical isomers proved relatively straightforward. Many strong candidates omitted to determine the formula of **A** or realised quite late on within their extended response that this was required.
			Total	**6**	
4			** Please refer to the marking instruction point 10 for guidance on how to mark this question.* **(Level 3)** Describes full details of all of the test procedures and observations that allows all four compounds identified. *There is a well-developed line of reasoning and the method is clear and logically structured. The information presented is relevant and substantiated by observations from the tests described.* (5–6 marks) **(Level 2)**	6	**Indicative scientific points may include** **Details of tests** To identify sulfates: • Ammonium ion test: on the sulfates already identified; warm with NaOH(aq) *followed by* • Universal indicator test: use of moist indicator paper on (ammonia) gas; correct observation (alkaline gas / high pH / blue or purple) for identification of $(NH_4)_2SO_4$, and by default of Na_2SO_4. To identify halides:

			Describes most of the tests in some detail including the observations that allows all four compounds to be identified. *There is a line of reasoning presented and the method has some structure. The information presented is in the most-part relevant and supported by some evidence of observations from the tests described.* (3–4 marks) **(Level 1)** Describes some of the tests but lacks details and observations to allow the identification of all four compounds. *The information is basic and the method lacks structure. The information is supported by limited evidence of the observations, the relationship to the evidence may not be clear.* (1–2 marks) **(0 marks)** No response or no response worthy of credit.		• Halide ion test: addition of silver nitrate solution to remaining two solutions; correct observation (white precipitate / cream precipitate) *followed by* • Solubility of precipitate: addition of dilute ammonia solution to halide precipitates; correct observation (silver chloride dissolves) enabling identification of NaC*l* and by default of KBr.
•			**Total**	**6**	
5			C	1 (AO2.3)	
			Total	**1**	
6		i	[$Cu(NH_3)4(H_2O)_2$] $^{2+}$ ✓ **TAKE CARE** with correct brackets, numbers and 2+ charge	1 (AO 2.4)	**ALLOW** +2 for charge **IGNORE** $[Cu(NH_3)_4]^{2+}$ H_2O and NH3 can be in either order, i.e. [$Cu(H_2O)_2(NH_3)_4$]$^{2+}$ **Examiner's Comments** This reaction of copper(II) ions with aqueous ammonia and the formula of the complex ion formed are part of the specification. Within this novel

					context, the molar mass had been provided as a clue. Less than half the candidates correctly gave the correct formula and it was noticeable how well this part discriminated across abilities. This was another example of many candidates being unable to apply their knowledge and understanding to a novel context.
		ii	**Formula of precipitate** $Cu(OH)_2$ ✓ **IGNORE** name: copper(II) hydroxide --- **Formula of gas** ;NH_3 ✓ **IGNORE** name: ammonia --- **Test for ammonia** Available only from a reasonable attempt for identifying the gas as NH_3, e.g. NH_4, NH_4+, NH_2, ammonia, ammonium (Moist/damp) indicator/litmus (paper) turns blue ✓ Moist/damp **NOT** required. Initial colour of litmus **NOT** required but *blue* is **CON**	3 (AO 2.3 ×3)	ALLOW $Cu(OH)_2(H_2O)_4$ **ALLOW** charges on Cu **AND** OH e.g. $Cu^{2+}(OH^-)_2$ ✓ **DO NOT ALLOW** unbalanced charges. e.g. $Cu(OH^-)_2$ ✗ --- **DO NOT ALLOW** correct test for NH_3 based on incorrect ID of the gas **NO ECF** for a test on the wrong gas (has to be test for NH_3) **DO NOT ALLOW** bleaches indicator **CON** **Examiner's Comments** Addition of NaOH(aq) to the Tutton's salt results in two reactions: precipitation of copper(II) hydroxide and a reaction of an ammonium ion, used to show its presence as a qualitative test. As with Question 4 (c) (i), this part discriminated very well with many candidates able to be rewarded with some of the marks. The formula of copper(II) hydroxide, as $Cu(OH)_2$ or $Cu(OH)_2(H_2O)_2$ were both acceptable. This was correct more often than the responses related to the ammonium ion. The formula of the gas formed in the reaction of NaOH(aq) with the

					ammonium ion caused problems, with NH_3 and its subsequent test with moist indicator turning blue seen much less than the reaction of $Cu^{2+}(aq)$ ions. Hydrogen (the 'squeaky pop test) and oxygen (relighting a glowing split) were common incorrect responses. This was another question in which referring back to the formula of the Tutton's salt would have revealed important clues.
		iii	**Reagent** $BaCl_2$ / barium chloride (solution) **OR** $Ba(NO_3)_2$ / barium nitrate (solution) **OR** Ba^{2+} (solution/aq) / barium ions ✓ **Observation** **white** precipitate/ppt ✓ Only available from soluble Ba^{2+} reagent **ALLOW** minor slips in formula of Ba^{2+} reagent, e.g. BaCl, $BaNO_3$	2 (AO 2.3 ×2)	**ALLOW** $Ba(OH)_2$ or other **soluble** Ba^{2+} compounds --- **IGNORE** test for other anions provided they do **NOT** interfere with SO_4^{2-} test **e.g.** **IGNORE** addition of $HCl/HNO_3/H^+$ **BUT DO NOT ALLOW** H_2SO_4 *Interferes with SO_4^{2-} test* **IGNORE** $Ag^+/AgNO_3$ **after** SO_4^{2-} test **DO NOT ALLOW before** SO_4^{2-} test **IGNORE** bubbling any gas through limewater **IGNORE** responses linked to CrO_4^{2-} *Not in Tutton's salt that student prepares* **Examiner's Comments** Th final part of Question 4 required candidates to identify the anion in the Tutton's salt as sulfate, and to

					recall that Ba^{2+} ions is used for the sulfate test to form a white precipitate. Any soluble barium compound was credited with barium chloride and nitrate being the commonest seen. As with earlier parts, this part discriminated very well. Most candidates who knew that barium ions were needed also collected the mark for the white precipitate observation. Over half the candidates did not score here, the most common errors being to repeat the test for the ammonium ion, or to use silver nitrate, clear confusion with the halide test.
			Total	**6**	
7			**D**	1	**Examiner's Comments** The correct answer was D. Many candidates were able to identify the green precipitate as $Fe(OH)_2$ and the white precipitate as $BaSO_4$. A few candidates suggested C, identifying $BaCl_2$ as the white precipitate, or B, identifying $Cu(OH)_2$ as the green precipitate.
			Total	**1**	