Inorganics in aqueous solutions

Acid-base chemistry

For each of the test tube reactions described below;

(a) Write a balanced symbol equation (including state symbols) for the reactions occurring,
(b) Describe what you would expect to observe.

1. Sodium hydroxide solution is added dropwise to an aqueous solution of copper(II) sulfate until present in excess.

Equation

(1 mark)

Observations

(1 mark)

2. Sodium hydroxide solution is added dropwise to an aqueous solution of iron(II) sulfate until present in excess.

Equation

(1 mark)

Observations

(1 mark)

3. Sodium carbonate solution is added dropwise to an aqueous solution of manganese(II) sulfate until present in excess.

Equation

(1 mark)

Observations

(1 mark)

4. Sodium carbonate solution is added dropwise to an aqueous solution of iron(III) chloride until present in excess.

Equation

(1 mark)

Observations

(1 mark)

5. Sodium hydroxide solution is added dropwise to an aqueous solution of chromium(III) sulfate until present in excess.

Equation(s)

(1 mark)

Observations

(1 mark)

Brønsted-Lowry or Lewis base?

A *Brønsted-Lowry base* is a proton acceptor. A *Lewis base* donates a pair of electrons. In each of the test tube reactions described below, ammonia acts either as a Brønsted-Lowry base or a Lewis base. Complete the descriptions by filling in the blanks labelled **1**-**10**.

(10 marks)

Aqueous aluminium ions

When an aqueous solution of ammonia is added dropwise to an aqueous solution of aluminium sulfate, a **1.** ..... is formed which does not dissolve on addition of excess ammonia.

Equation: $[Al(H_2O)_6]^{3+}(aq) + 3\ NH_3(aq) \rightleftharpoons [Al(H_2O)_3(OH)_3](s) + 3\ NH_4^+(aq)$

In this reaction, ammonia is acting as a **2.** .....

Aqueous cobalt ions

When an aqueous solution of ammonia is added dropwise to a pink solution of aqueous cobalt(II) chloride, a blue precipitate is formed initially.

Equation: $[Co(H_2O)_6]^{2+}(aq) + 2\ NH_3(aq) \rightleftharpoons$ **3.** ..... + **4.** .....

In this reaction, ammonia is acting as a Brønsted-Lowry base.

On adding excess ammonia solution, the blue precipitate re-dissolves to form a **5.** .....

..... (which is oxidised by air to a dark brown mixture containing Co(III) compounds.)

Equation: $[Co(H_2O)_4(OH)_2](s) + 6\ NH_3(aq) \rightleftharpoons [Co(NH_3)_6]^{2+}(aq) + 4\ H_2O(l) + 2\ OH^-(aq)$

In this second reaction, ammonia is acting as a **6.** .....

Aqueous copper ions

When an aqueous solution of ammonia is added dropwise to a blue solution of aqueous copper(II) sulfate, a **7.** ..... is initially formed.

Equation: $[Cu(H_2O)_6]^{2+}(aq) + 2\ NH_3(aq) \rightleftharpoons [Cu(H_2O)_4(OH)_2](s) + 2\ NH_4^+(aq)$

In this reaction, ammonia is acting as a Brønsted-Lowry base.

On the addition of excess ammonia solution, the **7.** ..... re-dissolves to form **8.** ..... .

Equation: $[Cu(H_2O)_4(OH)_2](s) + 4\ NH_3(aq) \rightleftharpoons$ **9.** ..... $+ 2\ H_2O(l) + 2\ OH^-(aq)$

In this second reaction, ammonia is acting as a **10.** .....

Ligand substitution reactions

For each of the criteria **1-5** below, identify a ligand substitution reaction starting from $[Cu(H_2O)_6]^{2+}$ and selecting ligands from NH_3, Cl^-, *en* ($H_2NCH_2CH_2NH_2$), $C_2O_4^{2-}$ and $EDTA^{4-}$ which meet the criteria required.

Choose a **different** reaction for each set of criteria, and in each case, draw a 3-dimensional representation of the final product.

1. No change in either the coordination number or the overall charge on the complex

2. No change in the coordination number of the complex but a change in the overall charge on the complex.

3. A change in both the coordination number and overall charge on the complex

4. The largest positive change in entropy

5. Produces a chiral product

(2 marks each)

Inference from aqueous tests

Use the results of the simple test tube reactions shown below to identify the anion and the cation in each of the unknown salts **A**-**E**. Each of the tests were carried out on a small sample of the salt dissolved in water.

	Salt A	**Salt B**	**Salt C**	**Salt D**	**Salt E**
Test 1 Add NaOH(aq) dropwise until present in excess	A green ppt formed which re-dissolved in excess to form a green solution	A pale blue ppt formed which did not re-dissolve in excess	A blue ppt formed which did not re-dissolve in excess	A green ppt formed which did not re-dissolve in excess	A brown ppt formed which did not re-dissolve in excess
Test 2 Add NH_3(aq) dropwise until present in excess	A green ppt formed which re-dissolved in excess to form a purple solution	A pale blue ppt formed which re-dissolved in excess to form a deep blue solution	A pale blue ppt formed which re-dissolved in excess to form a pale yellow / brown solution	A green ppt formed which slowed turned orange / brown on standing. No visible change with excess	A brown ppt formed which did not re-dissolve in excess
Test 3 Add CO_3^{2-}(aq) dropwise until present in excess	A green ppt formed. Effervescence. No visible change with excess	A blue green ppt formed. No visible change with excess	A pink ppt formed. No visible change with excess	A green ppt formed. No visible change with excess	A brown ppt formed. Effervescence. No visible change with excess
Test 4 Add HNO_3 followed by $AgNO_3$(aq)	No visible change	A white ppt formed which was observed to dissolve in dil. NH_3(aq)	A cream ppt formed which was observed to dissolve in conc. NH_3(aq)	A white ppt formed which was observed to dissolve in dil. NH_3(aq)	No visible change
Test 5 Add HCl followed by $BaCl_2$(aq)	A white ppt formed	No visible change	No visible change	No visible change	A white ppt formed

Salt A is (2 marks)

Salt B is (2 marks)

Salt C is (2 marks)

Salt D is (2 marks)

Salt E is (2 marks)

Inorganics in aqueous solution – Answers

Acid-base chemistry

(1 mark for each correct equation with state symbols; 1 mark for each correct full observation)

1. *Equation:* $[Cu(H_2O)_6]^{2+}(aq) + 2\ OH^-(aq) \rightleftharpoons [Cu(H_2O)_4(OH)_2](s) + 2\ H_2O(l)$
Observations: Blue solution to a blue precipitate which doesn't re-dissolve in excess NaOH.

2. *Equation:* $[Fe(H_2O)_6]^{2+}(aq) + 2\ OH^-(aq) \rightleftharpoons [Fe(H_2O)_4(OH)_2](s) + 2\ H_2O(l)$
Observations: Pale green solution to a murky green precipitate which is oxidised in the air to orange/brown $[Fe(H_2O)_3(OH)_3](s)$.

3. *Equation:* $[Mn(H_2O)_6]^{2+}(aq) + CO_3^{2-}(aq) \rightleftharpoons MnCO_3(s) + 6\ H_2O(l)$
Observations: Very pale pink solution to a very pale pink precipitate.

4. *Equation:* $2\ [Fe(H_2O)_6]^{3+}(aq) + 3\ CO_3^{2-}(aq) \rightleftharpoons 2\ [Fe(H_2O)_3(OH)_3](s) + 3\ H_2O(l) + 3\ CO_2(g)$
Observations: Yellow/brown solution to an orange/brown precipitate and effervescence.

5. *Equations:* $[Cr(H_2O)_6]^{3+}(aq) + 3\ OH^-(aq) \rightleftharpoons [Cr(H_2O)_3(OH)_3](s) + 3\ H_2O(l)$
$[Cr(H_2O)_3(OH)_3](s) + 3\ OH^-(aq) \rightleftharpoons [Cr(OH)_6]^{3-}(aq) + 3\ H_2O(l)$
Observations: Ruby or green solution to a green precipitate which dissolves in excess NaOH to form a green solution.

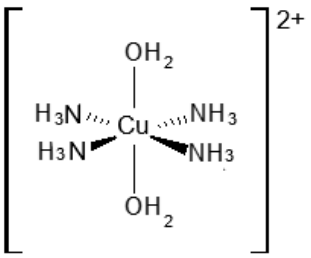
Brønsted-Lowry or Lewis base?

1. white precipitate
2. Brønsted-Lowry base
3. $[Co(H_2O)_4(OH)_2](s)$
4. $2\ NH_4^+(aq)$
5. pale yellow/brown solution
6. Lewis base
7. blue precipitate
8. deep blue solution
9. $[Cu(NH_3)_4(H_2O)_2]^{2+}$
10. Lewis base

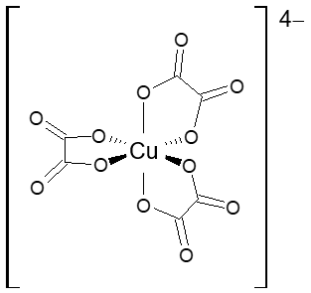
(10 marks)

Ligand substitution reactions

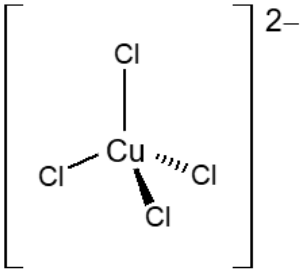
1. $[Cu(H_2O)_6]^{2+}(aq) + 4\ NH_3(aq) \rightleftharpoons [Cu(H_2O)_2(NH_3)_4]^{2+}(aq) + 4H_2O(l)$



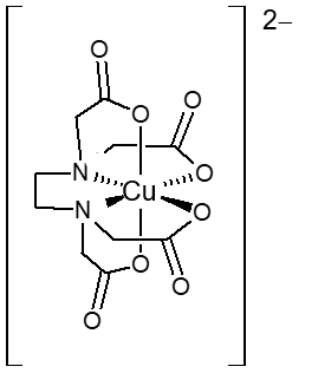
2. $[Cu(H_2O)_6]^{2+}(aq) + 3\ C_2O_4^{2-}(aq) \rightleftharpoons [Cu(C_2O_4)_3]^{4-}(aq) + 6\ H_2O(l)$



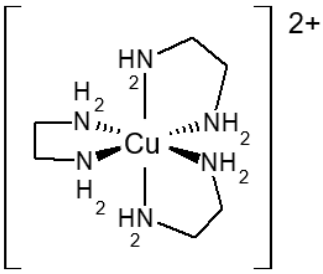
3. $[Cu(H_2O)_6]^{2+}(aq) + 4\ Cl^{-}(aq) \rightleftharpoons [CuCl_4]^{2-}(aq) + 6\ H_2O(l)$



4. $[Cu(H_2O)_6]^{2+}(aq) + EDTA^{4-}(aq) \rightleftharpoons [CuEDTA]^{2-}(aq) + 6\ H_2O(l)$



5. $[Cu(H_2O)_6]^{2+}(aq) + 3$ '*en*'$(aq) \rightleftharpoons [Cu$'*en*'$_3]^{2+}(aq) + 6\ H_2O(l)$



(1 mark for each correct equation, 1 mark for each correct drawing)

Inference from aqueous tests

Salt A is chromium(III) sulfate (2 marks)

Salt B is copper(II) chloride (2 marks)

Salt C is cobalt(II) bromide (2 marks)

Salt D is iron(II) chloride (2 marks)

Salt E is iron(III) sulfate (2 marks)