The Copper(II) Ion Reacts With Ammonia To Form A Deep Blue Copper Ammine Complex Ion. How Many Moles

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Understanding the reaction between Copper(II) ions and ammonia is fundamental in inorganic chemistry, especially in the context of complex formation, solution color changes, and qualitative analysis. This process results in the formation of a distinctive deep blue copper ammine complex ion, which is both visually striking and chemically significant. In this comprehensive guide, we will explore the nature of this reaction, the stoichiometry involved, and how to determine the number of moles of reactants required to produce a specific amount of the complex. Whether you're a student, educator, or chemistry enthusiast, this detailed discussion aims to clarify the underlying principles and practical calculations related to this iconic chemical transformation.

Understanding Copper(II) Ions and Ammonia

The Copper(II) Ion (Cu^{2+})

Copper(II) ions are common transition metal cations with the chemical formula Cu2+. They are typically encountered in aqueous solutions as blue-colored ions due to their d-d electronic transitions. Copper(II) salts such as copper sulfate, copper nitrate, or copper chloride readily dissolve in water, releasing Cu2+ ions into solution.

Key properties:

- Color in aqueous solution: Pale blue to deep blue depending on concentration
- Coordination behavior: Tends to form complexes with ligands such as ammonia, water, and others
- Oxidation state: +2, which is common for transition metals

Ammonia (NH_3) as a Ligand

Ammonia is a weak base and a common ligand in coordination chemistry. It can donate a lone pair of electrons to metal ions, forming coordinate covalent bonds. When ammonia interacts with metal ions like Cu2+, it leads to the formation of stable complexes.

Key points:

- Ammonia is a colorless gas with a pungent smell
- In aqueous solution, it exists in equilibrium with ammonium hydroxide (NH_4OH)
- Acts as a neutral ligand, donating a lone pair via its nitrogen atom

The Formation of the Deep Blue Copper Ammine Complex

The Basic Reaction

When ammonia is added to a solution containing Cu2+ ions, it initially forms a pale blue precipitate of copper(II) hydroxide, which dissolves upon excess ammonia to produce a stable complex.

The overall reaction can be summarized as:

$$Cu^{2+} + 4\ NH_3 \rightarrow [Cu(NH_3)_4]^{2+}$$

This complex, known as tetraamminecopper(II) ion, exhibits a vibrant deep blue color, characteristic of its coordination environment.

Coordination Number and Geometry

Copper(II) in this complex typically exhibits a coordination number of four, adopting a square planar or distorted tetrahedral geometry. The stability of this complex depends on the ligand environment and the conditions under which it forms.

Stoichiometry and Molar Calculations

Determining the Number of Moles of Reactants

To calculate how many moles of ammonia are required to react completely with a given amount of copper(II) ions, we rely on the stoichiometry of the balanced chemical equation.

- Balanced Equation:

$$Cu^{2+} + 4\ NH_3 \rightarrow [Cu(NH_3)_4]^{2+}$$

- Molar Ratio:
For every 1 mole of Cu2+, 4 moles of NH3 are needed.

Using this ratio, the calculation steps are:

1. Determine the moles of Cu2+ present in the solution.
2. Multiply the moles of Cu2+ by 4 to find the moles of ammonia required.

Example Calculation:

Suppose you have 0.05 mol of Cu2+ ions in solution.

- Moles of NH3 needed:

$$0.05 \text{ mol } Cu^{2+} \times 4 \text{ mol } NH_3/\text{mol } Cu^{2+} = 0.20 \text{ mol } NH_3$$

Therefore, 0.20 mol of ammonia are necessary to fully react with 0.05 mol of copper(II) ions, producing the deep blue complex.

Practical Applications and Laboratory Procedures

Preparation of the Copper Amine Complex

In a laboratory setting, preparing the deep blue copper ammine complex involves:

1. Adding a known volume of copper(II) salt solution to a reaction vessel.
2. Gradually adding concentrated ammonia solution while stirring.
3. Monitoring the color change from pale blue to deep blue, indicating complex formation.
4. Adjusting the amount of ammonia to reach the desired molar ratio based on calculations.

Quantitative Analysis

Using the molar ratios, chemists can:

- Determine the concentration of copper(II) ions in unknown samples by titration with ammonia.
- Calculate the amount of ammonia required for complete complexation.
- Use spectrophotometry to measure the intensity of the deep blue color, correlating it with the concentration of the complex.

Factors Affecting Complex Formation

pH and Concentration

The pH of the solution influences the formation of the complex:

- High pH favors complex formation by reducing competing hydrolysis reactions.
- Too high or too low pH can destabilize the complex or cause precipitation.

Excess Ammonia

Adding excess ammonia ensures complete complexation but must be controlled to prevent side reactions such as formation of other copper-ammonia complexes or precipitation of copper hydroxide.

Temperature

Elevated temperatures can affect the equilibrium position, potentially influencing the stability and color intensity of the complex.

Significance of the Copper Ammine Complex in Chemistry

Analytical Chemistry

The deep blue copper ammine complex serves as a qualitative and quantitative indicator in analytical procedures, assisting in the detection and measurement of copper ions.

Industrial Applications

It finds applications in:

- Electroplating processes
- Coordination chemistry research

- Educational demonstrations of complex formation

Historical and Educational Importance

The reaction is a classic example illustrating ligand field theory, coordination geometry, and molar calculations, making it a staple in inorganic chemistry curricula.

Summary and Key Takeaways

1. The reaction between Copper(II) ions and ammonia forms a deep blue tetraamminecopper(II) complex.

2. Stoichiometrically, 1 mole of Cu^{2+} reacts with 4 moles of NH_3.

3. Calculating the required moles of each reactant involves knowing the initial quantities and applying the molar ratio.

4. Experimental conditions such as pH, temperature, and concentration influence complex formation.

5. This reaction exemplifies key concepts in coordination chemistry and is useful in analytical applications.

In conclusion, understanding how many moles of ammonia are needed to react with a given amount of copper(II) ions to produce the deep blue complex is essential in both academic and practical chemistry. By applying stoichiometry and considering reaction conditions, chemists can accurately control and utilize this iconic complex formation in various contexts.

If you need specific calculations based on certain quantities or further details on related topics, feel free to ask!

Frequently Asked Questions

What is the chemical formula of the deep blue copper ammine complex formed when Copper(II) reacts with

ammonia?

The complex is typically $[Cu(NH_3)_4]^{2+}$.

How many moles of ammonia are needed to fully coordinate with one mole of Copper(II) ion in the formation of the deep blue complex?

Four moles of ammonia are required to coordinate with one mole of Copper(II) ion to form $[Cu(NH_3)_4]^{2+}$.

What is the balanced chemical equation for the reaction between Copper(II) ions and ammonia?

$Cu^{2+} + 4\ NH_3 \rightarrow [Cu(NH_3)_4]^{2+}$

How does the concentration of ammonia affect the formation of the Copper(II) ammine complex?

Higher concentrations of ammonia favor the formation of the deep blue $[Cu(NH_3)_4]^{2+}$ complex by shifting the equilibrium towards complex formation.

What is the significance of the deep blue color in the copper ammine complex in analytical chemistry?

The deep blue color serves as a visual indicator of the presence of Copper(II) ions and the formation of the ammine complex, aiding in qualitative and quantitative analysis.

Can the Copper(II) ammine complex be used in any practical applications?

Yes, it is used in analytical chemistry for detecting copper ions and in some cases as a precursor in chemical syntheses involving copper complexes.

Additional Resources

The Copper(II) Ion Reacts With Ammonia To Form A Deep Blue Copper Ammine Complex Ion. How Many Moles?

Introduction

Chemistry, especially inorganic chemistry, offers a fascinating exploration of how metal ions interact with various ligands to form complex ions with distinct properties. One of the most classic and visually striking examples involves the reaction of copper(II) ions with ammonia, resulting in the formation of a deep blue copper ammine complex ion. This reaction not only illustrates fundamental principles of coordination chemistry but also exemplifies how ligand coordination influences the electronic and geometric structure of metal centers.

This comprehensive review aims to dissect this reaction in detail, focusing on the stoichiometry involved—specifically, how many moles of ammonia are required to fully coordinate with a given amount of copper(II) ions. We will explore the underlying chemistry, the structure of the complex, the factors influencing complex formation, and practical considerations for calculating moles in laboratory settings.

The Chemistry of Copper(II) Ions and Ammonia

Copper(II) Ion Characteristics

- Electronic configuration: Copper(II) ions have the electron configuration [Ar] $3d^9$, which contributes to their paramagnetic nature and their ability to form various coordination complexes.
- Charge and size: Cu^{2+} ions carry a +2 charge and have a relatively small ionic radius, facilitating stable complex formation with ligands like ammonia.
- Hydration in aqueous solution: In water, Cu^{2+} typically exists as $[Cu(H_2O)_6]^{2+}$, a hexaaquacopper(II) complex, which exhibits characteristic pale blue color.

Ammonia as a Ligand

- Ligand properties: Ammonia (NH_3) is a neutral ligand with a lone pair on nitrogen, capable of donating this pair to a metal center, forming coordinate covalent bonds.
- Coordination behavior: Ammonia readily complexes with transition metals, stabilizing various oxidation states and geometries.
- Stability of complexes: The stability of copper-ammonia complexes depends on factors like ligand concentration, pH, and temperature.

The Formation of the Deep Blue Copper Ammine

Complex

Initial Hydration and Ligand Exchange

- Copper(II) ions in aqueous solution are surrounded by water molecules, forming $[Cu(H_2O)_6]^{2+}$.
- When ammonia is added, it can displace water molecules from the coordination sphere through ligand exchange.
- The process involves replacing water molecules with ammonia ligands, resulting in a series of complex ions with increasing numbers of ammonia ligands.

Progression of Complex Formation

The well-known copper-ammonia complex is:

$$
\text{[Cu(NH}_3)_4]^{2+}
$$

which exhibits a vivid deep blue color. The formation occurs through stepwise ligand substitution:

1. Formation of $[Cu(NH_3)_2]^{2+}$ (pale blue)
2. Formation of $[Cu(NH_3)_4]^{2+}$ (deep blue)
3. Potential further complexes, although the tetrammine complex is most stable under typical conditions.

Reaction Equation

The overall complexation can be summarized as:

$$
\text{Cu}^{2+} + 4\, \text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4]^{2+}
$$

This indicates that four moles of ammonia are required to fully coordinate with one mole of copper(II) ions to form the stable deep blue complex.

Stoichiometry and Moles of Ammonia

Understanding the Molar Ratios

- The key point in this reaction is the molar ratio between copper(II) ions and ammonia molecules.
- Based on the complex's chemical formula, the molar ratio is:

$$
\boxed{
\text{Cu}^{2+} : \text{NH}_3 = 1 : 4
}
$$

- This ratio reflects the number of ammonia molecules needed to fully coordinate each copper ion in the complex.

Calculating Moles in Practical Scenarios

Suppose a laboratory experiment involves:

- A known amount of copper(II) ions, say n mols.
- The goal is to determine how many moles of ammonia are required to completely form the deep blue complex.

Calculation:

$$
\text{Moles of NH}_3 = 4 \times \text{Moles of Cu}^{2+}
$$

Example:

If you start with 0.05 mol of Cu^{2+}:

$$
\text{Moles of NH}_3 = 4 \times 0.05 \text{ mol} = 0.20 \text{ mol}
$$

This calculation assumes complete reaction and no side reactions.

Factors Influencing the Reaction and Complex Formation

pH and Ammonia Concentration

- The pH of the solution affects ammonia's availability and the stability of complexes.
- Ammonia is a weak base; in excess, it maintains a high pH, favoring complex formation.
- At low pH, ammonia can be protonated to form ammonium (NH_4^+), reducing free ammonia available for complexation.

Temperature Effects

- Elevated temperatures can influence complex stability and reaction kinetics.
- Typically, complex formation is favored at lower temperatures, where the deep blue complex is most stable.

Ligand Concentration and Equilibrium

- Excess ammonia shifts the equilibrium towards complex formation.
- The formation constant (K_f) for $[Cu(NH_3)_4]^{2+}$ is quite high ($\sim 10^{13}$), indicating a very stable complex under typical conditions.

Competing Ligands and Side Reactions

- Other ligands or ions in solution may compete with ammonia for coordination sites.
- Presence of chloride ions or other complexing agents can alter the equilibrium.

Applications and Significance of the Copper-Ammonia Complex

- Analytical Chemistry: Used in qualitative analysis to detect copper ions via characteristic color changes.
- Industrial Processes: Employed in ore processing and electroplating.
- Educational Demonstrations: A common experiment to visualize ligand field theory and coordination chemistry.

Practical Laboratory Considerations

Preparation of the Complex

- Start with a copper(II) salt, such as copper sulfate ($CuSO_4$).
- Add ammonia solution gradually, observing color change from pale blue to deep blue.
- Ensure excess ammonia to drive the formation of the $[Cu(NH_3)_4]^{2+}$ complex.

Quantitative Analysis

- To determine the amount of ammonia needed, measure the initial moles of copper salt.
- Use the molar ratio (1:4) to calculate the required moles of ammonia.
- Adjust the volume and concentration of ammonia solution accordingly.

Safety Precautions

- Handle ammonia with care due to its pungent smell and corrosive nature.
- Use appropriate protective equipment: gloves, goggles, and lab coat.
- Work in a well-ventilated area or fume hood.

Summary

In conclusion, the reaction of copper(II) ions with ammonia to form the deep blue copper ammine complex involves a straightforward molar ratio: one mole of Cu^{2+} reacts with four moles of NH_3. This stoichiometric relationship is fundamental to understanding complex formation in coordination chemistry and enables precise calculations in laboratory and industrial applications.

The formation of $[Cu(NH_3)_4]^{2+}$ exemplifies how ligand coordination influences color, stability, and electronic properties of transition metal complexes. Recognizing this molar relationship allows chemists to design experiments, analyze samples, and innovate in fields ranging from analytical chemistry to materials science.

Understanding the detailed chemistry behind this reaction not only enhances comprehension of inorganic chemistry principles but also underscores the importance of molar ratios in predicting and controlling chemical reactions.

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Note: Always verify experimental conditions and constants like formation constants from reliable sources or experimental data when performing practical calculations.

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