A 1.25 G Sample Of Aluminum Is Reacted With 3.28 G Of Copper (II) Sulfate. What Is The Limiting Reactant?2Al(s)

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Understanding the concept of limiting reactants is fundamental in stoichiometry — the branch of chemistry that deals with the quantitative relationships between reactants and products in chemical reactions. In this comprehensive article, we delve into a specific problem involving aluminum and copper(II) sulfate, guiding you step-by-step through the process of identifying the limiting reactant. Whether you're a student preparing for exams or a chemistry enthusiast seeking clarity, this detailed exploration will enhance your grasp of reaction analysis and stoichiometric calculations.

Introduction to Limiting Reactants in Chemical Reactions

What Is a Limiting Reactant?

In a chemical reaction, reactants are combined in specific ratios to produce products. However, in practical scenarios, reactants are often present in unequal amounts. The limiting reactant is the substance that is completely consumed first, thus limiting the amount of product formed. Once it is depleted, the reaction stops, even if other reactants remain.

Why Is Identifying the Limiting Reactant Important?

- Predicts the maximum amount of product obtainable.
- Helps optimize industrial processes to minimize waste.
- Enables accurate calculations in laboratory experiments.
- Facilitates understanding of reaction efficiency and yield.

The Chemical Reaction Between Aluminum and Copper(II) Sulfate

Balanced Chemical Equation

The reaction between aluminum metal and copper(II) sulfate is a classic single displacement reaction:

$$ 3\, \mathrm{CuSO_4} + 2\, \mathrm{Al} \rightarrow 3\, \mathrm{Cu} + \mathrm{Al_2(SO_4)_3} $$

This equation indicates:
- 3 moles of copper sulfate react with 2 moles of aluminum.
- The products are copper metal and aluminum sulfate.

Understanding the Stoichiometry

Based on the balanced equation:
- Mole ratio of aluminum to copper sulfate: 2:3.
- Implication: For every 2 moles of aluminum, 3 moles of copper sulfate are required for complete reaction.

Calculating Moles of Reactants

Given Data:

- Aluminum sample mass: 1.25 grams
- Copper(II) sulfate sample mass: 3.28 grams

Calculating Moles of Aluminum

The molar mass of aluminum (Al):
$$ M_{Al} = 26.98\, \mathrm{g/mol} $$

Number of moles of aluminum:
$$ n_{Al} = \frac{\text{Mass of Al}}{\text{Molar mass of Al}} = \frac{1.25\, \mathrm{g}}{26.98\, \mathrm{g/mol}} \approx 0.0463\, \mathrm{mol} $$

Calculating Moles of Copper(II) Sulfate

The molar mass of copper(II) sulfate ($CuSO_4$):
- Copper (Cu): 63.55 g/mol
- Sulfur (S): 32.07 g/mol
- Oxygen (O): 16.00 g/mol (4 oxygens)

Total molar mass:

$$ M_{CuSO_4} = 63.55 + 32.07 + (4 \times 16.00) = 63.55 + 32.07 + 64.00 = 159.62\, \mathrm{g/mol} $$

Number of moles of copper sulfate:
$$ n_{CuSO_4} = \frac{3.28\, \mathrm{g}}{159.62\, \mathrm{g/mol}} \approx 0.0205\, \mathrm{mol} $$

Determining the Limiting Reactant

Applying Stoichiometry to Find the Limiting Reactant

From the balanced equation:
- 2 mol Al react with 3 mol $CuSO_4$.
- Therefore, the mole ratio:

$$ \frac{n_{Al}}{n_{CuSO_4}} = \frac{2}{3} \approx 0.6667 $$

Let's compare the actual mole ratio:
$$ \text{Actual ratio} = \frac{n_{Al}}{n_{CuSO_4}} = \frac{0.0463}{0.0205} \approx 2.26 $$

Since 2.26 is much greater than 0.6667, it indicates that:
- Aluminum is in excess.
- Copper(II) sulfate is the limiting reactant.

Conclusion: Copper(II) sulfate ($CuSO_4$) is the limiting reactant in this reaction.

Verifying the Limiting Reactant with Theoretical Yield Calculations

Calculating Theoretical Copper Produced

From the balanced equation:
- 3 mol $CuSO_4$ produce 3 mol Cu.
- Therefore, 0.0205 mol $CuSO_4$ will produce:

$$ n_{Cu} = 0.0205\, \mathrm{mol} $$

Mass of copper produced:
$$ M_{Cu} = 63.55\, \mathrm{g/mol} $$
$$ \text{Mass of Cu} = n_{Cu} \times M_{Cu} = 0.0205 \times 63.55 \approx 1.30\, \mathrm{g} $$

Expected maximum copper yield: approximately 1.30 grams.

Additional Considerations in Reaction Analysis

Reaction Efficiency and Yield

- Actual yields may be less than theoretical due to incomplete reactions, side reactions, or loss during processing.
- Calculating percentage yield:

$$ \% \text{Yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100 $$

Practical Implications of Limiting Reactants

- Ensuring the correct amounts of reactants can optimize product yield.
- Excess reactant remains unreacted, which might be wasteful or require purification.

Summary of Key Points

- The balanced chemical equation is essential for accurate calculations.
- Moles of reactants are calculated using their masses and molar masses.
- Comparing mole ratios determines the limiting reactant.
- Copper(II) sulfate is the limiting reactant in this specific reaction.
- The theoretical yield of copper is approximately 1.30 grams.

Final Thoughts and Practical Applications

Understanding limiting reactants is vital in both academic and industrial chemistry. It allows chemists to predict maximum product yields, optimize reaction conditions, and minimize waste. In processes such as metal extraction, pharmaceuticals, and manufacturing, precise stoichiometric calculations ensure efficiency and cost-effectiveness.

This detailed analysis of aluminum reacting with copper(II) sulfate demonstrates the fundamental principles of mole ratios, stoichiometry, and limiting reagents. By mastering these concepts, students and professionals can confidently approach complex chemical problems and make informed decisions in laboratory and industrial settings.

Keywords for SEO Optimization:
- Limiting reactant
- Stoichiometry
- Aluminum and copper sulfate reaction
- Chemical reaction calculations
- Moles and molar mass
- Copper sulfate limiting reactant
- Reaction yield
- Chemical balancing
- Industrial chemistry
- Metal displacement reactions

Remember: Always double-check your calculations and ensure your data (masses, molar masses) are accurate for precise results. Understanding the limiting reactant concept is fundamental to mastering chemical reaction analysis and optimizing laboratory and industrial processes.

Frequently Asked Questions

How do you determine the limiting reactant when aluminum reacts with copper(II) sulfate?

You compare the mole ratios of the reactants based on the balanced chemical equation to see which reactant runs out first, thereby identifying the limiting reactant.

What is the balanced chemical equation for the reaction between aluminum and copper(II) sulfate?

The balanced equation is $2Al(s) + 3CuSO_4(aq) \rightarrow 3Cu(s) + Al_2(SO_4)_3(aq)$.

How do you calculate the moles of aluminum in 1.25 g sample?

Divide the mass of aluminum by its molar mass: 1.25 g ÷ 26.98 g/mol ≈ 0.0463 mol.

How do you find the moles of copper(II) sulfate in 3.28 g sample?

Divide the mass of copper sulfate by its molar mass: 3.28 g ÷ 159.61 g/mol ≈ 0.0205 mol.

Based on the balanced equation, what is the mole ratio between aluminum and copper(II) sulfate?

The ratio is 2 mol Al : 3 mol $CuSO_4$.

Using the mole ratio, which reactant is limiting in this reaction?

Since 0.0463 mol Al requires (0.0463 mol × 3/2) ≈ 0.06945 mol $CuSO_4$, but only 0.0205 mol are present, copper(II) sulfate is the limiting reactant.

What is the significance of identifying the limiting reactant in this reaction?

It determines the maximum amount of product (copper) that can be formed and helps in calculating theoretical yields.

Can excess aluminum react after copper(II) sulfate is consumed?

Yes, since aluminum is in excess, it will remain unreacted after all copper(II) sulfate is used up.

What is the practical application of understanding limiting reactants in this reaction?

It helps in optimizing industrial processes, reducing waste, and accurately predicting product yields.

If you wanted to produce the maximum amount of copper metal, which reactant should you use as the limiting reactant?

Copper(II) sulfate, because it is the limiting reactant in this scenario, limiting the amount of copper produced.

Additional Resources

Understanding the Limiting Reactant in the Reaction Between Aluminum and Copper(II) Sulfate

In the realm of chemical reactions, particularly those involving multiple reactants, identifying the limiting reactant is crucial for predicting the amount of products formed and understanding the reaction's efficiency. The scenario where a 1.25 g sample of aluminum reacts with 3.28 g of copper(II) sulfate provides a classic example of this concept in action. This article delves into the analytical process required to determine which reactant is limiting, exploring the underlying chemistry, stoichiometry, and calculations involved in such an assessment.

Fundamentals of the Reaction: Aluminum and Copper(II) Sulfate

Chemical Equation and Reactants

The specific reaction under consideration involves aluminum metal reacting with copper(II) sulfate solution. The balanced chemical equation for this reaction is:

$$ 2Al(s) + 3CuSO_4(aq) \rightarrow 3Cu(s) + Al_2(SO_4)_3(aq) $$

This reaction is a single displacement (metathesis) reaction where aluminum displaces copper from its sulfate salt due to its higher reactivity. The key aspects include:

- Aluminum (Al): a metal with a high reactivity, capable of reducing copper(II) ions.
- Copper(II) sulfate ($CuSO_4$): an ionic compound providing Cu^{2+} ions.
- Products: elemental copper (Cu) and aluminum sulfate ($Al_2(SO_4)_3$).

Understanding the molar ratios from the balanced equation is essential for stoichiometric calculations and determining the limiting reactant.

Implications of the Reaction

This reaction exemplifies a redox process where aluminum acts as a reducing agent, losing electrons to form Al^{3+} ions, while Cu^{2+} ions gain electrons to form copper metal. Such reactions are fundamental in metallurgy and electrochemistry, illustrating how reactivity series and standard reduction potentials influence reaction outcomes.

Calculating Moles of Reactants

The Given Data

- Aluminum sample: 1.25 grams
- Copper(II) sulfate sample: 3.28 grams

Before determining the limiting reactant, it's necessary to convert these masses into moles using their molar masses:

- Molar mass of Al: approximately 26.98 g/mol
- Molar mass of $CuSO_4$: approximately 159.61 g/mol (Cu: 63.55 g/mol, S: 32.07 g/mol, O_4: 4×16.00 g/mol)

Conversion to Moles

1. Aluminum:

$$ \text{Moles of Al} = \frac{1.25 \text{ g}}{26.98 \text{ g/mol}} \approx 0.0463 \text{ mol} $$

2. Copper(II) sulfate:

$$ \text{Moles of CuSO}_4 = \frac{3.28 \text{ g}}{159.61 \text{ g/mol}} \approx 0.0205 \text{ mol} $$

These calculations reveal that, initially, there are approximately 0.0463 mol of Al and 0.0205 mol of $CuSO_4$ available for reaction.

Stoichiometric Ratios and Theoretical Reactant Requirements

Determining the Limiting Reactant

The balanced chemical equation indicates the molar ratio:

$$ 2 \text{ mol Al} : 3 \text{ mol CuSO}_4 $$

or, simplified, for every 2 mol of aluminum, 3 mol of copper sulfate are needed.

To find out how much of each reactant is required to fully react with the other:

- For the available 0.0463 mol of Al:

$$ \text{CuSO}_4 \text{ needed} = \frac{3}{2} \times 0.0463 \text{ mol} = 0.06945 \text{ mol} $$

- For the available 0.0205 mol of $CuSO_4$:

$$ \text{Al needed} = \frac{2}{3} \times 0.0205 \text{ mol} \approx 0.01367 \text{ mol} $$

Comparison:

- Aluminum available: 0.0463 mol (more than the 0.01367 mol needed to react completely with 0.0205 mol of $CuSO_4$)
- Copper sulfate available: 0.0205 mol (less than the 0.06945 mol needed to react with all aluminum)

Since the amount of $CuSO_4$ is insufficient to react with all of the aluminum present, copper(II) sulfate is the limiting reactant. It will be completely consumed first, limiting the amount of copper produced.

Conclusion:

The limiting reactant in this scenario is copper(II) sulfate.

Quantitative Analysis of the Reaction Outcomes

Calculating Theoretical Yield of Copper

Knowing that $CuSO_4$ is limiting allows us to predict the maximum amount of copper metal that can be formed.

- Moles of Cu produced:

$$ \text{Moles of Cu} = \text{Moles of CuSO}_4 \text{ reacted} = 0.0205 \text{ mol} $$

- Molar mass of Cu: 63.55 g/mol

- Mass of Cu produced:

$$ 0.0205 \text{ mol} \times 63.55 \text{ g/mol} \approx 1.304 \text{ g} $$

This is the theoretical maximum yield of copper metal based on the initial quantities.

Remaining Aluminum

Since aluminum is in excess, not all of it will react. The amount that reacts:

$$ \text{Al reacted} = \frac{2}{3} \times 0.0205 \text{ mol} \approx 0.01367 \text{ mol} $$

Mass of aluminum that reacts:

$$ 0.01367 \text{ mol} \times 26.98 \text{ g/mol} \approx 0.369 \text{ g} $$

Remaining aluminum:

$$ 1.25 \text{ g} - 0.369 \text{ g} \approx 0.881 \text{ g} $$

Summary:

- Copper produced: approximately 1.304 g
- Unreacted aluminum: approximately 0.881 g

Implications and Practical Significance

Industrial and Laboratory Applications

Identifying the limiting reactant is essential in both industrial processes and laboratory syntheses. It allows chemists and engineers to:

- Optimize reactant quantities to maximize yield
- Minimize waste and cost
- Understand reaction efficiency and kinetics

In metallurgical processes, for example, knowing which reactant limits the reaction can influence process design, cost calculations, and waste management.

Educational Significance

From an educational perspective, problems like this serve as valuable teaching tools for illustrating the importance of stoichiometry, molar ratios, and qualitative analysis in chemistry. They also reinforce the importance of careful calculations and critical thinking when analyzing chemical reactions.

Additional Considerations and Factors

Reaction Conditions and Real-World Variations

While calculations provide a theoretical framework, real-world reactions can deviate due to:

- Impurities in reactants
- Incomplete reactions or side reactions
- Variations in temperature and pressure
- Solvent effects in aqueous reactions

These factors can influence the actual yield and reaction completion, underscoring the importance of experimental validation.

Environmental and Safety Aspects

Handling metals and salts such as aluminum and copper sulfate requires adherence to safety protocols due to potential toxicity and environmental impact. Proper disposal and containment of waste products, like aluminum sulfate, are vital.

Conclusion

The analytical process applied to the reaction between aluminum and copper(II) sulfate reveals that copper(II) sulfate is the limiting reactant given the initial quantities. The calculations demonstrate that, with 1.25 g of aluminum and 3.28 g of copper sulfate, the maximum amount of copper metal that can be produced is approximately 1.304 grams. Recognizing the limiting reactant enables precise control over reaction outcomes, optimizing efficiency and yield in both laboratory and industrial contexts.

This example underscores the importance of stoichiometry as a foundational tool in chemistry, bridging theoretical understanding with practical applications. Whether in designing chemical syntheses, refining metallurgical processes, or conducting educational demonstrations, the ability to identify limiting reactants is an indispensable skill for chemists and engineers alike.

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