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Given The Following Reaction: CuO (s) + H2 (g) Cu (s) + H2O (g) If 250. L Of Hydrogen Gas Are Used To analyze the chemical process, it is essential to understand the fundamentals of the reaction, the stoichiometry involved, and the practical applications of this chemical transformation. This reaction exemplifies a reduction process where copper(II) oxide (CuO) reacts with hydrogen gas (H2) to produce metallic copper (Cu) and water vapor (H2O). In this article, we will delve into the details of this reaction, explore the calculations involved in quantifying reactants and products, and discuss its significance in industrial and laboratory settings.

Understanding the Reaction: CuO and Hydrogen Gas

Reaction Overview

This chemical reaction is a classic example of a reduction-oxidation (redox) process. Copper(II) oxide (CuO) acts as an oxidizing agent, accepting electrons from hydrogen gas, which serves as the reducing agent. The overall reaction can be written as:

$CuO\ (s) + H_2\ (g) \rightarrow Cu\ (s) + H_2O\ (g)$

In this process, solid copper metal is produced alongside water vapor, which may be in gaseous form depending on temperature and pressure conditions.

Significance of the Reaction

This reaction is vital in several contexts:
- Metallurgical processes: Extracting pure copper from its oxide ore.
- Laboratory synthesis: Demonstrating redox reactions and stoichiometry.
- Industrial applications: Producing copper metal and water vapor in controlled environments.

Calculating the Moles of Hydrogen Gas Used

Given Volume and Conditions

The problem states that 250 liters of hydrogen gas are used. To perform calculations accurately, assumptions about temperature and pressure are necessary, typically assuming standard temperature and pressure (STP), where:
- Temperature = 273.15 K
- Pressure = 1 atm
- 1 mol of gas occupies 22.4 liters at STP

Converting Volume to Moles

Using the molar volume at STP:

Number of moles of H_2 = Volume of H_2 / Molar volume
= 250 L / 22.4 L/mol
≈ 11.16 mol

This means approximately 11.16 moles of hydrogen gas are involved in the reaction.

Stoichiometry of the Reaction

Balanced Chemical Equation

The reaction is already balanced:

CuO (s) + H_2 (g) → Cu (s) + H_2O (g)

This indicates a 1:1 molar ratio between CuO and H_2, and between H_2 and H_2O.

Reactant and Product Quantities

- For every 1 mol of H_2 consumed, 1 mol of CuO reacts.
- The amount of water produced correlates directly with hydrogen consumption.

Given the moles of H_2 (≈11.16 mol), the reaction would theoretically consume an equal amount of CuO and produce the same amount of water vapor.

Mass and Volume Calculations

Mass of Copper Produced

Using molar mass:

- Molar mass of Cu = 63.55 g/mol

Mass of Cu produced:
= 11.16 mol × 63.55 g/mol
≈ 709.8 g

This indicates that approximately 709.8 grams of metallic copper can be produced from 250 L of hydrogen gas under the specified conditions.

Volume of Water Vapor Produced

Since water is produced as a gas (H_2O vapor), and assuming ideal gas behavior at STP:

Volume of H_2O vapor = moles of H_2O × molar volume
= 11.16 mol × 22.4 L/mol
≈ 250 L

Thus, the reaction produces approximately 250 liters of water vapor, matching the volume of hydrogen used, assuming all hydrogen is consumed.

Practical Applications and Industrial Relevance

Metallurgical Extraction of Copper

This reaction is fundamental in the smelting and refining of copper ores. Copper oxides are reduced to metallic copper using hydrogen, which is a cleaner alternative to carbon reduction methods, reducing sulfur dioxide emissions.

Hydrogen as a Reducing Agent

Hydrogen gas offers several advantages:
- Produces water instead of greenhouse gases like CO_2.
- Enables pure copper recovery.
- Suitable for environmentally friendly metal extraction processes.

Laboratory and Educational Uses

This reaction serves as an excellent demonstration of redox chemistry, stoichiometry, and gas-volume relationships at STP.

Additional Considerations

Reaction Conditions

- Temperature: Elevated temperatures favor the reduction process.
- Pressure: Increased pressure can influence gas volumes and reaction rates.
- Purity of reactants: Impurities can affect reaction efficiency.

Limitations and Safety

- Hydrogen gas is flammable and requires careful handling.
- Proper ventilation and safety protocols are necessary during experiments or industrial operations.

Summary and Conclusion

Analyzing the reaction between copper(II) oxide and hydrogen gas reveals how stoichiometry and gas laws interplay to determine reactant and product quantities. Using 250 liters of hydrogen gas at STP corresponds to roughly 11.16 moles, which theoretically produces about 709.8 grams of copper and 250 liters of water vapor. This process exemplifies efficient reduction techniques crucial in metal extraction industries, highlighting the importance of chemical calculations in practical applications.

In conclusion, understanding the quantitative aspects of this redox reaction enables chemists and engineers to optimize processes, predict yields, and design environmentally friendly methods for metal recovery. The reaction's simplicity, combined with its industrial significance, underscores the central role of stoichiometry and gas laws in modern chemistry.

Frequently Asked Questions

What is the balanced chemical equation for the reaction involving CuO and H_2?

The balanced equation is $CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(g)$.

How many moles of hydrogen gas are used if 250 L are provided at standard temperature and pressure (STP)?

At STP, 1 mol of gas occupies 22.4 L. Therefore, 250 L of H_2 corresponds to approximately 11.16 moles (250 ÷ 22.4).

What is the theoretical mass of copper metal produced from 250 L of hydrogen gas?

Using 11.16 mol of H_2, which reacts in a 1:1 ratio to produce 11.16 mol of Cu, the mass of Cu produced is 11.16 mol × 63.55 g/mol ≈ 710.5 grams.

How would the reaction shift if excess CuO is present?

If excess CuO is present, the reaction will proceed until all H_2 is consumed, producing maximum Cu and H_2O, with the limiting reagent being H_2.

What are the key factors influencing the reaction efficiency in this process?

Factors include temperature, pressure, purity of reactants, and surface area of CuO, which all affect reaction rate and completeness.

How can this reaction be utilized in industrial hydrogen production or metal extraction?

This reaction can be used in processes like copper ore reduction, where hydrogen acts as a reducing agent to produce pure copper, or in hydrogen storage systems.

What safety precautions should be taken when handling hydrogen gas in this reaction?

Hydrogen is flammable and explosive; proper ventilation, avoiding sparks or open flames, and using appropriate containment are essential safety measures.

Additional Resources

Given The Following Reaction: $CuO (s) + H_2 (g) \rightarrow Cu (s) + H_2O (g)$

This chemical reaction exemplifies a fundamental redox process with significant industrial and academic relevance. It involves the reduction of copper(II) oxide (CuO) by hydrogen gas (H_2) to produce metallic copper (Cu) and water vapor (H_2O). Understanding this reaction requires an exploration of its thermodynamics, kinetics, practical applications, and environmental implications. This review provides a comprehensive analysis of the reaction, focusing on the scenario where 250 liters of hydrogen gas are involved, and offers insights into the principles governing its behavior.

Understanding the Reaction: Basic Principles and Mechanism

Reaction Overview

The reaction:

$CuO\ (s) + H_2\ (g) \rightarrow Cu\ (s) + H_2O\ (g)$

is a typical reduction process where hydrogen acts as a reducing agent, donating electrons to copper(II) oxide, reducing it to metallic copper. Simultaneously, H_2 is oxidized to form water vapor. The reaction is generally carried out at elevated temperatures to facilitate kinetics and drive the thermodynamic equilibrium toward the products.

Thermodynamics and Equilibrium

The spontaneity of this reaction depends on temperature, pressure, and the partial pressure of H_2O. At high temperatures, the reduction of CuO by H_2 is favored, which aligns with Le Châtelier's principle, as removing water vapor from the system can shift the equilibrium toward product formation.

The standard Gibbs free energy change ($\Delta G°$) for the reaction can be derived from standard thermodynamic data, and it indicates that the process is thermodynamically favorable at elevated temperatures (typically above 250°C). This temperature dependence is crucial in industrial settings where precise control optimizes yield.

Quantitative Analysis: Using 250 Liters of Hydrogen Gas

Stoichiometry and Moles of Hydrogen

Given the volume of hydrogen gas used, we can determine the amount of reactant involved:

- Standard Conditions Assumption:
At standard temperature and pressure (STP), 1 mol of gas occupies approximately 22.4 liters.

- Calculating Moles of H_2:
Moles of H_2 = 250 L / 22.4 L/mol ≈ 11.16 mol

This calculation indicates that approximately 11.16 moles of hydrogen gas are available to react with CuO.

Mass of Hydrogen and Copper Yield

- Mass of Hydrogen:
Molar mass of H_2 = 2.02 g/mol
Mass of H_2 = 11.16 mol × 2.02 g/mol ≈ 22.56 grams

- Theoretical Copper Production:
The molar ratio of CuO to Cu is 1:1.
- Moles of Cu produced = 11.16 mol
- Molar mass of Cu = 63.55 g/mol
- Mass of Cu = 11.16 mol × 63.55 g/mol ≈ 709.3 grams

- Water Vapor Produced:
The water produced will be equal in molar amount to the hydrogen consumed, i.e., 11.16 mol of H_2O.
- Molar mass of H_2O = 18.02 g/mol
- Mass of H_2O = 11.16 mol × 18.02 g/mol ≈ 201.2 grams

This analysis is essential for industrial applications where material balances are critical.

Industrial Significance and Applications

Metal Extraction and Refining

The reduction of copper oxide with hydrogen is a common step in copper refining:

- Advantages:
- Produces high-purity copper without the need for smelting.
- Generates water vapor instead of harsh chemical waste.
- Can be performed in controlled atmospheres, minimizing contamination.

- Process Features:
- Often conducted at high temperatures (~300–400°C).
- Hydrogen gas can be generated on-site via electrolysis or steam reforming.

Environmental and Safety Considerations

Hydrogen is flammable and explosive under certain conditions, so safety protocols are paramount. The process's environmental footprint is relatively low, especially when hydrogen is produced sustainably.

Pros:

- Clean reduction process with water as the only byproduct.
- High selectivity for copper reduction.

Cons:

- Hydrogen handling poses safety risks.
- Energy-intensive hydrogen production if not sourced renewably.
- Requires high-temperature equipment.

Alternative Reduction Methods and Comparison

Other methods for reducing CuO include:

- Carbon reduction:
- Cheaper but produces CO or CO_2, leading to environmental concerns.

- Electrolytic reduction:
- Offers high purity but is energy-intensive and less practical at large scales.

Compared to these, hydrogen reduction provides a cleaner, more environmentally friendly route, though with higher operational costs.

Reaction Kinetics and Practical Considerations

Factors Influencing Reaction Rate

- Temperature: Elevated temperatures accelerate kinetics but must be optimized to prevent copper sintering or unwanted side reactions.
- Surface Area: Finely ground CuO reacts faster due to increased surface contact.
- Gas Flow Rate: Adequate hydrogen flow ensures uniform reaction and prevents local depletion.

Challenges in Industrial Implementation

- Maintaining consistent temperature and hydrogen flow.
- Handling high-temperature gases safely.
- Ensuring complete reaction to minimize residual CuO.

Environmental Impact and Sustainability

Green Aspects of Hydrogen Reduction

- When hydrogen is sourced from renewable energy, the reduction process becomes nearly carbon-neutral.
- Produces only water vapor as a byproduct, minimizing pollution.

Limitations and Challenges

- Current reliance on fossil fuels for hydrogen production increases carbon footprint.
- High energy consumption for hydrogen generation impacts sustainability.

Conclusion: Evaluating the Process

The reduction of copper oxide with hydrogen gas, exemplified by the reaction involving 250 liters of H_2, is a significant process in metallurgy and materials science. It offers high purity, environmentally friendly operation, and integration into modern manufacturing workflows. However, considerations around safety, energy consumption, and hydrogen sourcing are critical for its sustainable application.

Key features:

- Efficiency: High selectivity and minimal waste.
- Environmental benefits: Water vapor as the sole byproduct.
- Cost considerations: Hydrogen generation and process temperature control.

Pros:

- Produces high-purity copper suitable for electronic and industrial uses.

- Environmentally cleaner compared to traditional smelting.

Cons:

- Safety risks associated with hydrogen handling.
- Economic challenges related to hydrogen production and process energy demands.

In conclusion, leveraging this reaction at scale requires balancing technical, economic, and environmental factors. Advances in renewable hydrogen production and process optimization will determine its future role in sustainable metallurgy.

Note: This analysis assumes standard conditions; actual industrial conditions may vary, and detailed process design should consider specific parameters such as temperature, pressure, and material purity.

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