What Volume In Milliliters Of CO Gas Would Be Produced By The Complete Reaction Of 2.40 G Of C Solid

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Understanding the relationship between chemical reactions and gas volumes is fundamental in chemistry, especially in stoichiometry. When carbon (C) reacts completely with oxygen (O_2), it produces carbon monoxide (CO) gas, a key industrial chemical and a crucial component in various chemical processes. This guide aims to walk you through the step-by-step process of calculating the volume of CO gas generated from the complete combustion of 2.40 grams of solid carbon, emphasizing the importance of molar relationships, ideal gas laws, and precise calculations.

Introduction to the Reaction Between Carbon and Oxygen

Understanding the Chemical Equation

The core reaction involved in this process is the formation of carbon monoxide (CO) from carbon and oxygen:

$$ \text{C (s)} + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{CO (g)} $$

This balanced chemical equation indicates that one mole of carbon reacts with half a mole of oxygen gas to form one mole of carbon monoxide.

Key Concepts in Gas Volume Calculations

- Molar Volume of Gas: At standard temperature and pressure (STP), one mole of any ideal gas occupies approximately 22.4 liters (or 22,400 milliliters).
- Stoichiometry: The calculation of reactant and product quantities based on balanced chemical equations.
- Ideal Gas Law: PV = nRT, which relates pressure (P), volume (V), amount of substance (n), temperature (T), and gas constant (R). For calculations at STP, simplified assumptions are often used.

Step-by-Step Calculation Process

1. Calculate the Moles of Carbon (C) Reacted

Given:
- Mass of carbon, $m_{C} = 2.40\, \text{g}$
- Atomic mass of carbon, $M_{C} = 12.01\, \text{g/mol}$

Calculation:

$$
n_{C} = \frac{m_{C}}{M_{C}} = \frac{2.40\, \text{g}}{12.01\, \text{g/mol}} \approx 0.1998\, \text{mol}
$$

Result: Approximately 0.200 mol of carbon reacts completely.

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2. Determine the Moles of CO Produced

From the balanced equation:

$$
\text{C} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO}
$$

The molar ratio of C to CO is 1:1, so:

$$
n_{CO} = n_{C} \approx 0.200\, \text{mol}
$$

Result: 0.200 mol of CO gas is produced.

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3. Calculate the Volume of CO Gas at STP

At STP (Standard Temperature and Pressure):
- 1 mol of gas occupies 22,400 mL

Therefore:

$$
V_{CO} = n_{CO} \times 22,400\, \text{mL/mol} \approx 0.200\, \text{mol} \times 22,400\, \text{mL/mol} = 4,480\, \text{mL}
$$

Result: Approximately 4,480 milliliters of CO gas would be produced.

Additional Considerations in Gas Volume Calculations

Adjustments for Non-STP Conditions

While STP provides a standard reference, actual laboratory conditions often differ. To account for this:

- Use the ideal gas law: $V = \frac{nRT}{P}$
- Adjust for temperature (T) and pressure (P) deviations

For example, at a temperature of 25°C (298 K) and pressure of 1 atm, the molar volume is approximately 24.45 liters (24,450 mL), slightly higher than at STP.

Impacts of Reaction Completeness

- Complete reaction assumptions are crucial; incomplete reactions result in less CO.
- Reaction conditions, such as oxygen availability, temperature, and catalyst presence, influence reaction completeness.

Environmental and Safety Implications

- CO is a toxic gas; proper handling and ventilation are essential.
- Industrial processes often involve controlled environments to manage CO production safely.

Real-World Applications of Carbon Monoxide Production

Industrial Synthesis and Uses

- Metallurgical Processes: CO is used in reduction reactions, such as extracting metals from their ores.
- Chemical Manufacturing: It serves as a building block for synthesizing acetic acid, methanol, and

other chemicals.
- Fuel and Energy: CO can be used as a fuel source in certain combustion processes.

Environmental Considerations

- CO emissions contribute to air pollution and pose health risks.
- Catalytic converters and emission controls are employed to reduce CO release.

Summary of Key Points

- Reacting 2.40 grams of carbon produces approximately 0.200 mol of CO gas.
- Under STP conditions, this molar amount corresponds to roughly 4,480 mL of CO gas.
- Understanding molar relationships and gas laws enables precise calculations of gas volumes from solid reactants.
- Environmental safety and reaction conditions significantly influence actual CO production and handling.
- Applications of CO span industrial manufacturing, energy production, and chemical synthesis, with safety considerations paramount.

Conclusion

Calculating the volume of gases produced in chemical reactions bridges fundamental chemistry principles with practical applications. In the specific case of the complete reaction of 2.40 grams of solid carbon with oxygen, approximately 4,480 milliliters of carbon monoxide gas are generated under standard conditions. This calculation underscores the importance of understanding stoichiometry, gas laws, and reaction conditions to accurately predict product quantities in both laboratory and industrial settings. Proper safety protocols and environmental awareness are essential when dealing with gases like CO, ensuring that chemical processes benefit society while minimizing risks.

Note: Always verify conditions (temperature, pressure) for precise calculations, especially in real-world applications where deviations from STP are common.

Frequently Asked Questions

How do you determine the volume of CO gas produced from the complete reaction of 2.40 g of carbon solid?

First, convert 2.40 g of carbon to moles, then use the stoichiometry of the reaction ($C + O_2 \rightarrow CO$) to find moles of CO produced, and finally apply the ideal gas law at standard conditions to convert moles to volume in milliliters.

What is the balanced chemical equation for the reaction of carbon with oxygen to produce carbon monoxide?

The balanced equation is $C + \frac{1}{2} O_2 \rightarrow CO$, which indicates that 1 mole of carbon reacts with half a mole of oxygen to produce 1 mole of carbon monoxide.

How many moles of carbon are present in 2.40 g of solid carbon?

Using the molar mass of carbon (12.01 g/mol), the number of moles is 2.40 g ÷ 12.01 g/mol ≈ 0.1998 mol.

What volume in milliliters of CO gas would be produced at standard temperature and pressure (STP)?

At STP, 1 mole of gas occupies 22.4 liters. Therefore, 0.1998 mol of CO would occupy approximately 4.48 liters, or 4480 milliliters.

What assumptions are made when calculating the volume of CO gas produced in this reaction?

It is assumed that the gas behaves ideally, the reaction goes to completion without side reactions, and the temperature and pressure are at standard conditions (0°C and 1 atm).

Additional Resources

What Volume In Milliliters Of CO Gas Would Be Produced By The Complete Reaction Of 2.40 G Of C Solid

Understanding the quantitative aspects of chemical reactions is fundamental in chemistry, bridging the gap between theoretical calculations and practical applications. When examining the complete conversion of solid carbon (C) into carbon monoxide (CO) gas, it is essential to quantify the amount of gaseous product formed, particularly in units convenient for laboratory and industrial settings, such as milliliters (mL). This article provides a comprehensive analysis of how to determine the volume of CO gas produced from 2.40 grams of carbon, incorporating detailed stoichiometric calculations, molar concepts, gas laws, and considerations for real-world applications.

Introduction to the Reaction: Carbon and Its Conversion to Carbon Monoxide

In many industrial processes, carbon undergoes oxidation to generate various gaseous products, notably carbon monoxide (CO), which serves as a crucial intermediate in manufacturing fuels, chemicals, and metallurgy. The reaction of solid carbon with oxygen or other oxidizing agents typically proceeds as follows:

$C (s) + ½ O_2 (g) \rightarrow CO (g)$

This exothermic reaction highlights the conversion of carbon from a solid to a gaseous form, with a 1:½ molar ratio between carbon and oxygen, resulting in the formation of carbon monoxide.

Significance of Carbon Monoxide Production

- Industrial Uses: CO is utilized in the production of methanol, acetic acid, and as a reducing agent in metallurgy.
- Environmental Concerns: CO is a toxic, colorless, odorless gas, emphasizing the importance of understanding its generation and control.
- Analytical Applications: Quantifying CO production assists in process optimization, safety assessments, and environmental monitoring.

Step-by-Step Calculation Framework

Determining the volume of CO gas produced involves several key steps:

1. Calculating the moles of carbon reacted
2. Applying the stoichiometric relationship to find moles of CO produced
3. Using gas laws to convert moles into volume at specified conditions

This systematic approach ensures accurate, reproducible calculations and helps interpret the results in practical contexts.

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1. Calculating Moles of Carbon Reacted

Given data:

- Mass of carbon (C) = 2.40 g

- Atomic mass of carbon (C) ≈ 12.01 g/mol

Calculation:

$$
\text{Moles of C} = \frac{\text{Mass of C}}{\text{Atomic mass of C}} = \frac{2.40\, \text{g}}{12.01\, \text{g/mol}} \approx 0.1998\, \text{mol}
$$

For simplicity, this is approximately 0.200 mol of carbon.

---

2. Determining Moles of CO Formed

From the balanced reaction:

$$
\text{C (s)} + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{CO (g)}
$$

The molar ratio of carbon to CO is 1:1. Therefore:

$$
\text{Moles of CO} = \text{Moles of C} \approx 0.200\, \text{mol}
$$

This means that 0.200 mol of carbon will produce approximately 0.200 mol of CO gas upon complete reaction.

---

3. Calculating the Volume of CO Gas at Standard Conditions

The volume of a gas is related to the number of moles via the ideal gas law:

$$
PV = nRT
$$

Where:

- P = pressure
- V = volume
- n = number of moles
- R = ideal gas constant (8.314 J/mol·K)
- T = temperature in Kelvin

Standard Temperature and Pressure (STP) conditions are typically:

- Temperature $T = 273.15\, \text{K}$
- Pressure $P = 1\, \text{atm}$

At STP, 1 mol of any ideal gas occupies 22.4 liters (L).

Calculating the volume:

$$
V = n \times 22.4\, \text{L/mol}
$$

$$
V = 0.200\, \text{mol} \times 22.4\, \text{L/mol} = 4.48\, \text{L}
$$

Converting liters to milliliters:

$$
V = 4.48\, \text{L} \times 1000\, \text{mL/L} = 4480\, \text{mL}
$$

Result: Approximately 4480 mL (or 4.48 liters) of CO gas would be produced under standard conditions from 2.40 g of carbon.

Considerations and Real-World Implications

While the above calculation provides a fundamental theoretical estimate, several factors influence the actual volume of CO gas generated in practical settings.

Conditions Deviating from STP

- Temperature Variations: Industrial reactions often occur at elevated temperatures, which increase gas volume proportionally.
- Pressure Variations: Higher pressures compress gases, reducing volume; lower pressures expand gases.
- Non-Ideal Gas Behavior: At high pressures or low temperatures, gases deviate from ideality, necessitating corrections via real gas equations.

If the reaction occurs at a temperature T' and pressure P', the volume can be adjusted using the ideal gas law:

$$
V' = \frac{nRT'}{P'}
$$

\]

or by applying correction factors based on real gas behavior.

Efficiency and Completeness of Reaction

In laboratory or industrial processes, complete conversion of carbon to CO may not occur due to:

- Incomplete reactions
- Side reactions forming CO_2
- Impurities in reactants
- Reaction kinetics and temperature control

Therefore, actual yields are typically less than theoretical maximums.

Safety and Environmental Concerns

Handling gaseous CO requires stringent safety measures due to its toxicity. Accurate calculations of expected gas volumes aid in designing appropriate ventilation, detection systems, and safety protocols.

Broader Context and Applications

The calculation of the volume of CO produced from a given mass of carbon exemplifies core principles in chemical stoichiometry, ideal gas law applications, and process optimization.

Industrial Significance

- Syngas Production: CO is a key component in synthesis gas (syngas), used to manufacture a variety of chemicals.
- Fuel Generation: In processes like gasification, understanding CO volume helps in designing reactors and estimating fuel outputs.
- Environmental Monitoring: Quantifying CO emissions enables better regulation and mitigation of pollution.

Educational and Analytical Value

- Demonstrates practical application of stoichiometry and gas laws.
- Serves as a foundation for more complex process simulations and safety assessments.

Conclusion

In summary, the complete reaction of 2.40 grams of solid carbon produces approximately 4480 milliliters (or 4.48 liters) of carbon monoxide gas under standard conditions. This calculation underscores the importance of stoichiometric principles in predicting gaseous products and highlights the interconnectedness of chemical reactions, gas laws, and real-world applications. Whether in industrial settings, environmental assessments, or educational laboratories, understanding how to quantify gaseous outputs from solid reactants remains a vital skill in chemistry.

The ability to accurately estimate gas volumes not only aids in process design and safety but also deepens our understanding of chemical transformations, emphasizing the pivotal role of quantitative analysis in advancing scientific and industrial endeavors.

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