

A 21.8 G Sample Of Ethanol (C₂H₅OH) Is Burned In A Bomb Calorimeter According To The Following Reaction.

A 21.8 G Sample Of Ethanol (C₂H₅OH) Is Burned In A Bomb Calorimeter According To The Following Reaction. This scenario provides a valuable opportunity to explore the principles of calorimetry, thermochemistry, and the energy content of ethanol. In this comprehensive article, we will delve into the details of ethanol combustion, the significance of bomb calorimetry, calculation methods for heat release, and the broader implications for energy research and environmental considerations.

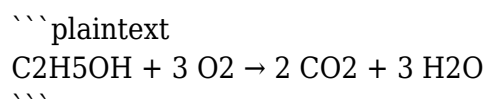
Understanding Ethanol and Its Combustion Reaction

What Is Ethanol?

Ethanol, also known as ethyl alcohol, is a volatile, flammable liquid with the chemical formula C₂H₅OH. It is widely used as a fuel additive, solvent, and in alcoholic beverages. Its combustion releases energy, making it a potential renewable energy source.

The Combustion Reaction of Ethanol

The combustion of ethanol in oxygen can be represented by the chemical equation:



This reaction indicates that one mole of ethanol reacts with three moles of oxygen to produce two moles of carbon dioxide and three moles of water, releasing heat in the process.

Role of Bomb Calorimetry in Measuring Combustion Energy

What Is Bomb Calorimetry?

Bomb calorimetry is an experimental technique used to measure the heat of combustion of a substance. It involves burning a sample within a sealed, oxygen-rich container called a "bomb" placed inside a water bath. The calorimeter measures temperature changes, which are then used to determine the heat released during combustion.

Why Use Bomb Calorimetry for Ethanol?

Since ethanol is flammable and releases significant energy upon combustion, bomb calorimetry provides an accurate way to quantify its energy content, known as the heat of combustion (ΔH_{comb}). This data is essential for assessing ethanol's viability as a fuel.

Calculating the Heat of Combustion of Ethanol

Step 1: Determine Moles of Ethanol Burned

Given the mass of ethanol:

- Mass of ethanol, $m = 21.8 \text{ g}$
- Molar mass of ethanol, $M = (2 \times 12.01) + (6 \times 1.008) + (16.00) = 46.068 \text{ g/mol}$

Number of moles:

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```plaintext
n = m / M = 21.8 g / 46.068 g/mol ≈ 0.4734 mol
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Step 2: Measure Temperature Change

In an actual experiment, the calorimeter records the temperature change (ΔT) of the water bath. For example, suppose the temperature increases by 4.5°C during the combustion.

Step 3: Calculate Heat Released (q)

The heat released is related to the temperature change:

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q = C_calorimeter × ΔT
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Where $C_{\text{calorimeter}}$ is the heat capacity of the entire calorimeter system, including water and the calorimeter itself. Assume, for example, that:

- $C_{\text{calorimeter}} = 10,000 \text{ J/}^\circ\text{C}$
- $\Delta T = 4.5^\circ\text{C}$

Then:

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q = 10,000 J/°C × 4.5°C = 45,000 J
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Step 4: Determine the Molar Enthalpy of Combustion

The molar heat of combustion (ΔH_{comb}) is:

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$$\Delta H_{\text{comb}} = q / n$$

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Plugging in the values:

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$$\Delta H_{\text{comb}} = 45,000 \text{ J} / 0.4734 \text{ mol} \approx 95,089 \text{ J/mol} \approx 95.1 \text{ kJ/mol}$$

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Since combustion is exothermic, the value is typically expressed as a negative number:

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$$\Delta H_{\text{comb}} \approx -95.1 \text{ kJ/mol}$$

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This indicates that burning one mole of ethanol releases approximately 95.1 kilojoules of energy.

Significance of Ethanol's Combustion Energy

Energy Content and Fuel Efficiency

The heat of combustion value helps in evaluating ethanol's energy density compared to other fuels like gasoline or diesel. Ethanol's energy content is lower than gasoline (~31.6 MJ/L for ethanol vs. ~34.2 MJ/L for gasoline), but its renewable nature and cleaner emissions make it an attractive alternative.

Environmental Considerations

Ethanol combustion produces fewer pollutants such as sulfur oxides and particulate matter. However, it still releases CO₂, contributing to greenhouse gases. Understanding its energy content aids in balancing energy needs with environmental impact.

Broader Implications and Applications

Biofuel Production

Ethanol is primarily produced through fermentation of biomass, such as corn or sugarcane. Quantifying its energy content through calorimetry supports its role as a sustainable renewable fuel source.

Energy Policy and Economics

Accurate measurements of ethanol's heat of combustion influence policies promoting biofuels, impact pricing strategies, and guide investments in ethanol-based energy infrastructure.

Research and Development

Ongoing research aims to improve ethanol yields, develop better combustion engines optimized for ethanol, and enhance ethanol's energy density through additives or blending.

Key Factors Affecting Calorimetric Measurements

Purity of Ethanol

Impurities can affect the combustion process and lead to inaccurate energy measurements. High-purity ethanol ensures reliable data.

Calorimeter Calibration

Proper calibration of the calorimeter's heat capacity is crucial for precise results.

Complete Combustion

Ensuring complete combustion in the experimental setup guarantees that all energy released is measured accurately.

Conclusion

Burning a 21.8 g sample of ethanol in a bomb calorimeter provides critical insight into its energy content, with practical applications spanning energy production, environmental management, and scientific research. Understanding the thermochemistry of ethanol combustion helps in optimizing its use as a renewable fuel, assessing its environmental impact, and advancing sustainable energy solutions. As research progresses, precise calorimetric measurements will continue to play a vital role in harnessing ethanol's full potential as an alternative energy source.

Additional Resources

- Books: Thermochemistry: Principles and Applications by J. Smith
- Websites: U.S. Department of Energy - Bioenergy Technologies Office
- Research Papers: "Calorimetric Measurement of Ethanol Combustion" in the Journal of Energy Chemistry

By comprehensively understanding the principles outlined in this article, scientists, engineers, and

policymakers can better evaluate ethanol's role in future energy landscapes, ensuring sustainable and environmentally friendly energy solutions.

Frequently Asked Questions

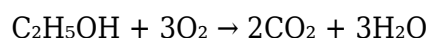
What is the significance of using a bomb calorimeter to measure the combustion of ethanol?

A bomb calorimeter allows for precise measurement of the heat released during ethanol combustion at constant volume, enabling accurate determination of the enthalpy change for the reaction.

How do you calculate the heat released during the combustion of 21.8 g of ethanol in a bomb calorimeter?

First, find the molar mass of ethanol (46.07 g/mol), then determine the number of moles burned (21.8 g / 46.07 g/mol). Multiply the molar enthalpy change (ΔH) for combustion by the number of moles to find the total heat released.

What is the balanced chemical equation for the combustion of ethanol?



How can the calorimeter data be used to determine the molar enthalpy of combustion of ethanol?

By measuring the temperature change in the calorimeter and knowing its heat capacity, you can calculate the total heat released. Dividing this by the number of moles burned gives the molar enthalpy of combustion.

What assumptions are typically made when calculating energy changes in a bomb calorimeter experiment?

Assumptions include that all heat released is absorbed by the calorimeter, no heat is lost to surroundings, and the system is at constant volume throughout the reaction.

Why is ethanol considered a good model compound for studying combustion reactions?

Ethanol is a simple, well-characterized alcohol with a straightforward combustion reaction, making it ideal for calorimetric studies and thermodynamic calculations.

What are common sources of error in calorimetry experiments involving ethanol combustion?

Errors can arise from heat loss to surroundings, incomplete combustion, inaccurate temperature measurements, or impurities in the sample, affecting the accuracy of the results.

How does the molar enthalpy of combustion of ethanol compare with other alcohols?

The molar enthalpy of combustion generally increases with the length of the carbon chain; ethanol's value is moderate compared to longer-chain alcohols, which release more energy upon combustion.

Additional Resources

Comprehensive Review of Burning a 21.8 g Sample of Ethanol in a Bomb Calorimeter

Introduction to the Experiment and Its Significance

Understanding the combustion of ethanol ($\text{C}_2\text{H}_5\text{OH}$) in a bomb calorimeter is fundamental in thermochemistry, providing insights into energy changes associated with chemical reactions. This experiment involves burning a precisely measured 21.8 g sample of ethanol within a controlled environment—specifically, a bomb calorimeter—to determine the heat released during combustion. Such data are essential for various applications, including biofuel research, energy production, and thermodynamic analysis.

This review aims to explore the detailed methodology, theoretical underpinnings, calculations, and interpretation of results associated with this experiment, emphasizing the importance of each step and the implications of the findings.

Understanding the Basic Concepts

What is a Bomb Calorimeter?

A bomb calorimeter is a device designed to measure the heat of combustion of a substance at constant volume. It consists of:

- A strong, insulated container (the "bomb") where the reaction occurs.
- An oxygen atmosphere to facilitate complete combustion.

- A surrounding water bath to absorb heat released.
- Sensitive temperature sensors to detect temperature changes.

The primary purpose is to quantify the energy change (usually in joules or calories) during a chemical reaction, which can then be related to molar or mass-based properties.

The Chemistry of Ethanol Combustion

The combustion of ethanol in oxygen proceeds according to the following balanced chemical reaction:



This reaction releases energy in the form of heat, which is absorbed by the water bath surrounding the bomb, leading to a measurable temperature increase.

Preparation and Procedure

Sample Measurement and Handling

- Precise weighing: 21.8 g of ethanol is measured using an analytical balance to ensure accuracy.
- Purity considerations: The purity of ethanol must be high (typically 99.5% or higher) to ensure the validity of the thermodynamic calculations.
- Sample placement: The ethanol sample is introduced into a crucible inside the bomb calorimeter, and the system is sealed.

Calibration of the Calorimeter

Before conducting the main experiment, calibration using a known standard (such as benzoic acid) is often performed to determine the calorimeter's heat capacity, C_{cal} . This step ensures that subsequent measurements of temperature change accurately reflect the heat released or absorbed.

Conducting the Combustion

- The ethanol sample is ignited electrically.
- The reaction occurs at constant volume within the sealed bomb.
- The heat released raises the temperature of the water bath and the calorimeter.
- The temperature change, ΔT , is recorded with high precision sensors.

Theoretical Foundations and Calculations

Determining the Heat of Combustion

The main goal is to find the heat released during combustion, denoted as q . It can be expressed as:

$$q = C_{\text{cal}} \times \Delta T$$

where:

- C_{cal} is the calorimeter's heat capacity (known from calibration).
- ΔT is the observed temperature increase during combustion.

Once q is obtained, it can be normalized to the amount of ethanol burned to derive the molar or mass-based heat of combustion.

Calculating Moles of Ethanol Burned

Given the mass of ethanol:

$$\text{Mass} = 21.8 \text{ g}$$

and molar mass of ethanol:

$$M_{\text{C}_2\text{H}_5\text{OH}} = (2 \times 12.01) + (6 \times 1.008) + (16.00) = 46.068 \text{ g/mol}$$

Number of moles:

$$n = \frac{21.8 \text{ g}}{46.068 \text{ g/mol}} \approx 0.473 \text{ mol}$$

The heat of combustion per mole is then:

$$\Delta H_{\text{comb}} = \frac{q}{n}$$

Interpreting Results and Thermodynamic Implications

Standard Enthalpy of Combustion

The experimental value, often expressed in kilojoules per mole, provides an approximation of the standard enthalpy of combustion ($\Delta H^{\circ}_{\text{comb}}$) for ethanol. Literature values typically hover around -1367 kJ/mol, but experimental data may vary due to:

- Calibration accuracy
- Sample purity
- Heat losses or gains during the experiment
- Measurement precision

Energy Content and Practical Applications

The energy released per gram of ethanol is a vital metric for:

- Evaluating biofuel efficiency
- Designing engines and combustion systems
- Comparing ethanol's energy density to other fuels

For instance, the energy content per gram:

$$\frac{\Delta H_{\text{comb}}}{\text{g}} = \frac{1367 \text{ kJ/mol}}{46.068 \text{ g/mol}} \approx 29.7 \text{ kJ/g}$$

indicates ethanol's substantial energy density relative to other renewable fuels.

Thermodynamic Considerations

- The experiment assumes complete combustion, meaning no incomplete oxidation or side reactions.
- The process is conducted at constant volume; thus, the measured heat corresponds mainly to the change in internal energy (ΔU) with minor corrections for work done.
- The relation between ΔU and ΔH involves the change in moles of gases, which is generally small for ethanol combustion but should be considered in detailed calculations.

Sources of Error and Experimental Challenges

Despite meticulous planning, several factors can influence the accuracy:

- Heat Losses: Despite the insulation, some heat may escape to the surroundings.
- Calibration Errors: Inaccurate calibration leads to incorrect C_{cal} values.
- Sample Impurities: Impurities alter the thermodynamic properties and energy release.
- Incomplete Combustion: Due to oxygen deficiency or inadequate ignition.

- Measurement Uncertainty: Variability in temperature readings, weighing, and timing.

Recognizing and minimizing these errors is crucial for reliable data.

Broader Implications and Future Directions

The combustion of ethanol serves as a model for understanding biofuel energetics, contributing to sustainable energy discussions. Accurate thermochemical data enable:

- Improved biofuel formulations with optimized energy content.
- Environmental impact assessments, considering the CO₂ emissions per unit energy.
- Advancements in calorimetry techniques, enhancing precision.

Future research may focus on:

- Comparing ethanol's combustion properties under different conditions.
- Investigating ethanol blends with other biofuels.
- Developing more sophisticated calorimetry methods to reduce uncertainties.

Conclusion

Burning a 21.8 g sample of ethanol in a bomb calorimeter is a classic yet profound experiment that bridges theoretical thermodynamics with practical energy measurements. It not only provides a quantifiable measure of ethanol's energy content but also deepens our understanding of combustion processes, fuel efficiency, and environmental impacts. Accurate execution, careful calibration, and thorough analysis are paramount for deriving meaningful and reliable data. As renewable energy sources gain prominence, such foundational experiments will continue to underpin innovations in sustainable fuel technology and thermochemical research.

In essence, this detailed exploration underscores the importance of precise experimental design, meticulous calculations, and critical interpretation in thermochemistry, exemplified through the combustion of ethanol in a bomb calorimeter.

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