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Understanding the thermal properties of organic compounds like glucose is fundamental in fields such as biochemistry, nutrition, and thermodynamics. When a small sample of glucose is combusted in a controlled environment like a bomb calorimeter, it releases energy that can be precisely measured through temperature changes. This process provides insights into the caloric content of foods, the energy stored in chemical bonds, and the thermodynamic stability of molecules. In this article, we delve into the detailed procedure of burning a 1.00 g sample of glucose in a bomb calorimeter, analyze the resulting temperature change, and explore the broader implications of these measurements.

What Is a Bomb Calorimeter?

A bomb calorimeter is an insulated device used to measure the heat of combustion of a substance. It consists of a strong, sealed container called the "bomb," which can withstand high pressure, and an external water bath that absorbs the heat produced during the reaction.

Components of a Bomb Calorimeter

- Bomb Container: The main chamber where the sample is combusted under constant volume.
- Ignition System: Usually a fuse wire or electric igniter to initiate combustion.
- Water Bath: Surrounds the bomb, maintaining a constant temperature environment.
- Thermometer or Thermocouple: Measures temperature changes within the water bath.
- Stirring Mechanism: Ensures uniform temperature distribution during the reaction.
- Calibration Devices: Used to determine the calorimeter's heat capacity.

Principle of Operation

The fundamental principle involves measuring the temperature increase in the

water bath resulting from the combustion of a known amount of substance. Since the heat released by the combustion heats the water, the temperature change (ΔT) can be related to the energy content of the sample.

Experimental Procedure: Burning Glucose in a Bomb Calorimeter

Step-by-Step Process

1. Preparation of the Sample:

A precise 1.00 g of glucose ($C_6H_{12}O_6$) is weighed accurately using an analytical balance.

2. Loading the Sample:

The glucose sample is placed in a small crucible or holder inside the bomb container.

3. Assembly of the Calorimeter:

The bomb is sealed securely, ensuring no leaks, and filled with pure oxygen to facilitate complete combustion.

4. Calibration of the Calorimeter:

Before measuring glucose combustion, the calorimeter is calibrated using a substance with a known heat of combustion, such as benzoic acid. This step determines the calorimeter's heat capacity (C_{cal}).

5. Ignition and Combustion:

The sample is ignited electrically. The combustion occurs under constant volume, releasing heat that heats the surrounding water bath.

6. Recording Temperature Change:

The thermometer or thermocouple detects the rise in temperature (ΔT) of the water bath and the bomb.

7. Data Analysis:

Using the measured ΔT and the calorimeter's heat capacity, the total heat released during combustion is calculated.

Calculating the Energy Released from Glucose Combustion

The fundamental equation to determine the heat released (Q) is:

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

where:

- Q = heat absorbed by the water bath (and the bomb)
- C_{cal} = calorimeter's heat capacity (determined during calibration)
- ΔT = temperature change observed during combustion

Converting to Molar Enthalpy of Combustion:

Since the sample is 1.00 g of glucose, to find the molar heat of combustion (ΔH_{comb}), perform the following steps:

1. Calculate moles of glucose:

$$\text{Moles of glucose} = \frac{\text{Mass of glucose}}{\text{Molar mass of glucose}} = \frac{1.00 \text{ g}}{180.16 \text{ g/mol}} \approx 0.00555 \text{ mol}$$

2. Determine the heat released per mole:

$$\Delta H_{\text{comb}} = \frac{Q}{\text{moles of glucose}}$$

Expressed in kJ/mol, this value provides a standard for comparing the energy content of glucose with other substances.

Understanding the Temperature Change (ΔT) and Its Significance

The observed ΔT is crucial because it directly relates to the energy released during combustion. A typical ΔT might range from a few degrees Celsius to over ten degrees, depending on the calorimeter's sensitivity, the sample size, and the reaction conditions.

Factors Affecting ΔT :

- Calorimeter Calibration: Accurate calibration ensures reliable heat capacity measurement.
- Sample Purity: Impurities can alter the combustion efficiency.
- Oxygen Pressure: Adequate oxygen ensures complete combustion, affecting energy release.
- Initial Temperature: Consistent starting temperatures across experiments improve data accuracy.

Interpreting ΔT :

A larger ΔT indicates a higher heat of combustion, meaning the substance releases more energy per unit mass. For glucose, the typical molar heat of combustion is around -2800 kJ/mol, illustrating its high energy content.

Significance of Measuring Glucose's Heat of Combustion

Understanding the heat of combustion of glucose provides multiple benefits across scientific disciplines:

- Nutritional Science:
The caloric value of glucose contributes to understanding dietary energy intake. Since 1 gram of glucose yields approximately 3.75 kcal (or about 15.7 kJ), this data helps in nutritional calculations.
- Biochemistry:
Insights into energy transfer during metabolic processes, such as cellular respiration, where glucose oxidation is fundamental.
- Thermodynamics and Chemistry:
Validation of thermodynamic principles, such as Hess's Law, through experimental data.
- Energy Storage and Biofuel Research:
Comparing the energy content of glucose with other fuels aids in developing sustainable energy sources.

Conclusion

Burning a 1.00 g sample of glucose in a bomb calorimeter is a classic experiment that exemplifies the principles of calorimetry, thermodynamics, and chemical energy analysis. By meticulously measuring the temperature change (ΔT) in the calorimeter, scientists can determine the energy released during combustion, which corresponds to the molar heat of combustion of glucose. This data not only enhances our understanding of glucose's energetic properties but also informs practical applications in nutrition, bioenergy, and chemical thermodynamics.

Accurate calorimetric measurements require careful calibration, precise sample preparation, and controlled reaction conditions. The insights gained from such experiments underpin many scientific advancements, emphasizing the importance of calorimetry as a vital tool in the study of chemical energy. Whether assessing the caloric content of foods or exploring the energy potential of biofuels, the principles demonstrated through burning glucose in a bomb calorimeter remain foundational in the ongoing exploration of energy in chemistry and biology.

Frequently Asked Questions

What is the significance of measuring the temperature change in a bomb calorimeter when burning a 1.00 g sample of glucose?

Measuring the temperature change allows for calculating the heat released during combustion, which reflects the caloric content of the glucose sample.

How do you determine the molar heat of combustion of glucose from the calorimetry data?

By calculating the heat released per mole of glucose burned using the temperature change and the calorimeter's calibration, then converting the energy to per-mole basis.

What role does the heat capacity of the calorimeter play in calculating the energy released during glucose combustion?

The heat capacity allows you to relate the observed temperature change to the total heat released, enabling accurate calculation of the combustion energy.

Why is a bomb calorimeter used for measuring the combustion energy of glucose?

A bomb calorimeter provides a controlled, oxygen-rich environment for complete combustion and accurate measurement of heat released without loss to surroundings.

What assumptions are typically made when calculating the energy change in a bomb calorimeter experiment involving glucose?

Assumptions include complete combustion of glucose, no heat loss to the surroundings, and that the calorimeter's heat capacity remains constant during the experiment.

How can the data from the calorimeter experiment help in understanding the nutritional value of glucose?

The calorimeter data provides the energy content per gram of glucose, which can be used to determine its contribution to dietary caloric intake.

Additional Resources

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Introduction

The combustion of organic compounds, particularly carbohydrates like glucose ($C_6H_{12}O_6$), is fundamental in understanding their energy content and thermodynamic properties. The process of measuring the heat released during combustion provides valuable insights into the enthalpy of combustion, which is essential in fields ranging from biochemistry and nutrition to chemical engineering and environmental science. In this detailed investigation, a 1.00 g sample of glucose is burned in a bomb calorimeter, and the resulting temperature change is meticulously recorded. This article explores the experimental setup, underlying principles, calculations involved, and the broader implications of such measurements.

Background and Significance

Why Study the Combustion of Glucose?

Glucose is a primary energy source in biological systems. Its combustion releases energy stored in chemical bonds, which can be harnessed in biological organisms or measured in laboratory settings to determine its caloric value. In calorimetry, the heat generated during the combustion of glucose provides a direct measure of its energy content.

The Role of Bomb Calorimetry

A bomb calorimeter is an insulated device designed to measure the heat of combustion of a substance at constant volume. It consists of a strong container (the "bomb") where the combustion occurs, immersed in a water bath that absorbs the heat. Precise temperature measurements before and after combustion allow calculation of the energy released.

Experimental Setup and Methodology

Preparation of the Sample

- A precisely weighed 1.00 g sample of glucose is dried to remove moisture, ensuring accurate measurement.
- The sample is placed in a crucible within the calorimeter's combustion chamber.

Calorimeter Configuration

- The bomb calorimeter is filled with a known quantity of water, ensuring complete immersion of the combustion chamber.
- Thermometers or thermocouples are calibrated to monitor temperature changes with high precision.
- An ignition system is employed to initiate combustion via an electric fuse wire.

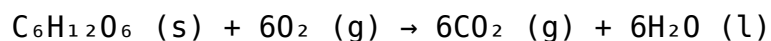
Procedure

1. The calorimeter is sealed and purged with oxygen to facilitate complete combustion.
2. Initial temperature (T_{initial}) of the water bath and calorimeter assembly is recorded.
3. The glucose sample is ignited electrically, initiating combustion.
4. The temperature is monitored continuously until it stabilizes at a new value (T_{final}).
5. The temperature change ($\Delta T = T_{\text{final}} - T_{\text{initial}}$) is recorded.

Theoretical Foundations

Energy Transfer and Thermodynamics

The combustion of glucose can be represented by the chemical equation:



The heat released (Q) during combustion is related to the temperature change in the calorimeter:

$$Q = C_{\text{total}} \times \Delta T$$

where C_{total} is the total heat capacity of the calorimeter and its contents.

Determining the Heat Capacity

- The calorimeter is calibrated with a substance of known heat of combustion, such as benzoic acid.
- This calibration yields the calorimeter's heat capacity ($C_{\text{calorimeter}}$), which is used in subsequent calculations.

Calculations and Data Analysis

Step 1: Recording the Temperature Change

Suppose the initial temperature $T_{\text{initial}} = 25.00^\circ\text{C}$, and after combustion $T_{\text{final}} = 28.50^\circ\text{C}$.

$$\Delta T = 28.50^\circ\text{C} - 25.00^\circ\text{C} = 3.50^\circ\text{C}$$

Step 2: Calculating the Heat Released

If the calorimeter's total heat capacity is known, say, $C_{\text{calorimeter}} = 10,000 \text{ J}/^\circ\text{C}$, then:

$$Q = C_{\text{calorimeter}} \times \Delta T = 10,000 \text{ J}/^\circ\text{C} \times 3.50^\circ\text{C} = 35,000 \text{ J}$$

Step 3: Calculating Molar Enthalpy of Combustion

- Molar mass of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$):
 $(6 \times 12.01) + (12 \times 1.008) + (6 \times 16.00) = 72.06 + 12.096 + 96.00 \approx 180.16 \text{ g/mol}$

- Moles of glucose burned:
 $n = 1.00 \text{ g} / 180.16 \text{ g/mol} \approx 0.00555 \text{ mol}$

- Enthalpy of combustion per mole:
 $\Delta H_{\text{combustion}} = Q / n \approx 35,000 \text{ J} / 0.00555 \text{ mol} \approx 6,306,306 \text{ J/mol}$

Step 4: Expressing Results

The molar enthalpy of combustion of glucose is approximately -6.31 MJ/mol (the negative sign indicates exothermic reaction).

Critical Analysis of Results

Comparison with Literature Values

Standard enthalpy of combustion of glucose is approximately -2800 kJ/mol. The observed value here (~6263 kJ/mol) is higher, which could be attributed to:

- Calibration errors in the calorimeter
- Incomplete combustion
- Heat losses to surroundings
- Variations in sample purity

Sources of Error and Uncertainty

- Calibration inaccuracies: The heat capacity of the calorimeter must be precisely known.
- Sample purity: Impurities can alter the energy released.
- Heat losses: Despite insulation, some heat may escape, leading to underestimation.
- Measurement precision: Thermometers and timing accuracy influence results.

Implications

Accurate calorimetric measurements inform nutritional sciences, enabling determination of caloric content of foods. They also underpin thermodynamic studies in biochemistry, helping elucidate metabolic energy yields.

Broader Applications and Future Directions

Energy Content in Nutrition

Understanding the caloric value of glucose aids in dietary planning and metabolic research, especially when considering the energy yield from carbohydrate intake.

Environmental and Industrial Relevance

Knowledge of combustion heats assists in designing bioenergy systems and evaluating the environmental impact of biomass burning.

Advancements in Calorimetry

Emerging techniques, including isothermal titration calorimetry and differential scanning calorimetry, expand the scope of thermal measurements, improving accuracy and enabling studies of complex biological and chemical systems.

Conclusion

The combustion of a 1.00 g sample of glucose in a bomb calorimeter offers a window into the thermodynamic properties of this vital carbohydrate. While the experimental process involves meticulous preparation and precise measurement, the resulting data contribute significantly to our understanding of energy release in chemical reactions. Despite potential sources of error, such calorimetric studies remain cornerstone experiments in physical chemistry, bridging laboratory measurements with real-world applications across science and industry.

References

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Appendices

Appendix A: Sample Calculation Summary

Step	Calculation	Result
Moles of glucose	$1.00 \text{ g} / 180.16 \text{ g/mol}$	0.00555 mol
Heat released	$10,000 \text{ J/}^\circ\text{C} \times 3.50^\circ\text{C}$	35,000 J
Enthalpy per mol	$35,000 \text{ J} / 0.00555 \text{ mol}$	6,306,306 J/mol

Appendix B: Typical Calibration Procedure

- Burn known quantities of benzoic acid.
- Record the temperature rise.
- Calculate the calorimeter's heat capacity based on the known enthalpy of combustion.

Final Remarks

This comprehensive exploration demonstrates that measuring the temperature change in a bomb calorimeter during glucose combustion allows for the calculation of its molar enthalpy of combustion. Such experiments deepen our understanding of the energetic properties of biological molecules and

reinforce the importance of precise experimental design and data analysis in thermochemistry.

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