A 17.05 Gram Sample Of An Organic Compound Containing C,H And O Is Analyzed By Combustion Analysis And

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In the realm of organic chemistry, accurately determining the empirical or molecular formula of an unknown compound is crucial for understanding its structure, reactivity, and properties. One common and effective method employed for this purpose is combustion analysis. When a 17.05-gram sample of an organic compound containing carbon (C), hydrogen (H), and oxygen (O) is subjected to combustion analysis, chemists can obtain vital quantitative data about the elemental composition of the compound. This process involves burning the sample in excess oxygen and measuring the amounts of combustion products—primarily carbon dioxide (CO_2) and water (H_2O). These measurements enable the calculation of the percentage composition of each element within the original sample, ultimately leading to the determination of its empirical formula. This article explores the methodology of combustion analysis, the calculations involved, and how to interpret the results to elucidate the compound's molecular structure.

Understanding Combustion Analysis of Organic Compounds

What Is Combustion Analysis?

Combustion analysis, also known as elemental analysis, is a quantitative technique used to determine the percentage of carbon, hydrogen, and oxygen in an organic compound. The process involves burning a known mass of the sample in pure oxygen or air, producing combustion gases that are then collected and measured. The main goal is to find the amounts of CO_2 and H_2O produced, which directly relate to the amounts of carbon and hydrogen in the original sample.

Principles of Combustion Analysis

The core principles of combustion analysis are based on stoichiometry and the conservation of mass. When the organic compound burns:
- Carbon is converted into carbon dioxide (CO_2)
- Hydrogen is converted into water (H_2O)
- Oxygen in the original compound is typically inferred from the difference in the total mass after accounting for the other elements

The general combustion reactions are:

- $C + O_2 \rightarrow CO_2$
- $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

By measuring the masses of CO_2 and H_2O produced, chemists can back-calculate the quantities of carbon and hydrogen present in the original sample.

Experimental Procedure for Combustion Analysis

Preparation of the Sample

- The sample (17.05 g) is weighed accurately using a precision balance.
- It is then placed in a combustion chamber or sample holder designed for complete combustion.

Combustion Process

- The sample is ignited in a controlled environment with excess oxygen.
- The combustion gases are passed through various absorption agents to trap CO_2 and H_2O separately.
- The gases are then quantified, often using techniques such as gravimetric analysis or infrared spectroscopy.

Measurement of Combustion Products

- Carbon dioxide (CO_2): Captured and weighed as calcium carbonate or analyzed via gas absorption methods.
- Water (H_2O): Absorbed in desiccants or measured via moisture analysis methods.

Data Collection and Calculations

- The masses of CO_2 and H_2O are used to calculate the moles of carbon and hydrogen in the original sample.
- The remaining mass of the sample is used to infer the oxygen content.

Calculations in Combustion Analysis

Calculating Elemental Percentages

Suppose the measurements yield:
- Mass of CO_2 produced: m_{CO2}
- Mass of H_2O produced: m_{H2O}

The steps to calculate the percentages are:

1. Calculate moles of carbon:
$$
n_C = \frac{m_{CO2}}{44.01\, \text{g/mol}}
$$
Since each mole of CO_2 contains one mole of carbon:
$$
m_C = n_C \times 12.01\, \text{g/mol}
$$

2. Calculate moles of hydrogen:
$$
n_{H} = \frac{m_{H2O}}{18.02\, \text{g/mol}}
$$
Each mole of H_2O contains two moles of hydrogen:
$$
m_H = n_{H} \times 2 \times 1.008\, \text{g/mol}
$$

3. Determine oxygen content:
- Total mass of the sample: 17.05 g
- Sum of masses of C and H: $m_C + m_H$
- Oxygen mass:
$$
m_O = 17.05\, \text{g} - (m_C + m_H)
$$
- Percentage of each element:
$$
\% C = \frac{m_C}{17.05} \times 100
$$
$$
\% H = \frac{m_H}{17.05} \times 100
$$
$$
\% O = \frac{m_O}{17.05} \times 100
$$

Deriving the Empirical Formula

Once the percent compositions are known, the empirical formula can be deduced by:
- Converting percentages to moles.
- Dividing each element’s mole count by the smallest among them.
- Multiplying by a factor to get whole numbers if necessary.

For example, if the mole ratios approximate to C_3H_6O, that would be the empirical formula.

Interpreting Results and Determining Molecular Formula

Empirical vs. Molecular Formula

- The empirical formula provides the simplest whole-number ratio of atoms.
- To find the molecular formula, the molar mass of the compound is needed, often determined via techniques like mass spectrometry.

The molecular formula is:

$$
\text{Molecular formula} = (\text{Empirical formula}) \times n
$$

where $n = \frac{\text{Molecular weight of compound}}{\text{Empirical formula weight}}$.

Application of Combustion Analysis Data

Suppose you obtained the following data after analysis:
- CO_2 produced: 8.13 g
- H_2O produced: 1.80 g

Calculations:
- Moles of C: $\frac{8.13}{44.01} \approx 0.1847$ mol
- Moles of H: $\frac{1.80}{18.02} \approx 0.0999$ mol
- Mass of C: $0.1847 \times 12.01 \approx 2.22\, \text{g}$
- Mass of H: $0.0999 \times 1.008 \times 2 \approx 0.201\, \text{g}$
- Mass of O: $17.05 - (2.22 + 0.201) \approx 14.63\, \text{g}$

Percentages:
- C: $\frac{2.22}{17.05} \times 100 \approx 13.03\%$
- H: $\frac{0.201}{17.05} \times 100 \approx 1.18\%$
- O: $\frac{14.63}{17.05} \times 100 \approx 85.79\%$

Molar ratios lead to an empirical formula, which can then be used to determine the molecular structure.

Significance and Applications of Combustion Analysis

Advantages of Combustion Analysis

- High accuracy for elemental determination
- Suitable for small and large samples

- Widely applicable for organic compounds

Limitations

- Cannot directly detect elements like nitrogen or halogens
- Requires specialized equipment
- Time-consuming compared to modern spectroscopic techniques

Broader Applications

- Pharmaceutical compound analysis
- Polymer and material characterization
- Quality control in chemical manufacturing

Conclusion

Combustion analysis remains a fundamental technique in organic chemistry, providing vital data for structural elucidation. For a 17.05 g sample containing C, H, and O, careful measurement of combustion products allows chemists to determine the elemental composition with high precision. This information is essential for deducing empirical formulas and, when combined with molecular weight data, the molecular formula. Understanding the principles and calculations behind combustion analysis empowers chemists to characterize unknown compounds accurately, advancing research and quality control across various chemical industries.

Keywords: combustion analysis, organic compound, empirical formula, elemental analysis, molecular formula, C H O, combustion products, stoichiometry, organic chemistry techniques, structural determination

Frequently Asked Questions

What is the purpose of combustion analysis in determining the composition of an organic compound?

Combustion analysis is used to determine the empirical formula of an organic compound by measuring the amounts of CO_2 and H_2O produced during combustion, which allows calculation of the carbon and hydrogen content.

How is the amount of oxygen in the compound calculated after combustion analysis?

Oxygen content is determined by subtracting the combined mass of carbon and hydrogen from the total sample mass, or by analyzing the amount of CO_2 and

H_2O produced and using stoichiometry.

Given a 17.05 g sample, how do you determine the empirical formula of the compound?

Calculate moles of C, H, and O from the combustion data, then divide each by the smallest number of moles to find the simplest whole-number ratio, which gives the empirical formula.

What are common errors to watch out for during combustion analysis of organic compounds?

Common errors include incomplete combustion, loss of samples, contamination, or improper calibration of measurement devices, all of which can lead to inaccurate results.

How does the presence of oxygen within the organic compound affect combustion analysis results?

The presence of oxygen in the compound is inferred from the difference after accounting for C and H content; it does not produce measurable combustion products directly but influences the calculation of the empirical formula.

How can the combustion analysis results be used to deduce the molecular formula of the compound?

Once the empirical formula is known, the molecular weight can be determined using additional data such as molar mass from other methods, and the molecular formula is found by multiplying the empirical formula by the appropriate factor.

What safety precautions should be taken during combustion analysis of organic compounds?

Proper ventilation, use of safety goggles and gloves, and handling of combustion gases safely are essential to prevent inhalation of harmful fumes and ensure laboratory safety.

Additional Resources

A 17.05 Gram Sample Of An Organic Compound Containing C, H, And O Is Analyzed By Combustion Analysis

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Introduction

Combustion analysis, also known as elemental analysis, is a fundamental technique used by chemists to determine the empirical formula of an organic compound. When dealing with a sample such as a 17.05-gram specimen containing carbon (C), hydrogen (H), and oxygen (O), this method allows for precise quantification of each element within the compound. Understanding the process, calculations, and implications of combustion analysis is crucial for organic chemists, particularly in fields such as pharmaceuticals, polymers, and environmental chemistry.

This detailed review will explore the step-by-step methodology of combustion analysis, interpret the typical data obtained, perform calculations to deduce the empirical formula, and discuss the significance and limitations of this technique.

Fundamentals of Combustion Analysis

what is combustion analysis?

Combustion analysis involves burning a known mass of an organic compound in excess oxygen, converting all carbon to carbon dioxide (CO_2), hydrogen to water (H_2O), and, if oxygen is present in the compound, the oxygen content is inferred indirectly. The process provides data on the mass of each combustion product, which can then be used to calculate the amount of each element in the original sample.

Why is combustion analysis important?

- Determines empirical formulas: Provides the simplest whole-number ratio of elements.
- Confirms molecular formulas: When combined with molecular weight data.
- Quality control: Ensures the purity and composition of synthesized compounds.
- Research applications: Assists in structure elucidation and verification.

Step-by-Step Combustion Procedure

1. Sample Preparation

- Accurate weighing of the sample: In this case, 17.05 g of the organic compound.
- Ensuring the sample is free of moisture or contaminants that could skew results.

2. Combustion Process

- The sample is introduced into a combustion chamber, often a sealed, oxygen-rich environment.

- Complete combustion is achieved by burning the sample at high temperatures, typically in a pure oxygen atmosphere.
- The combustion products (CO_2 and H_2O) are collected separately.

3. Collection and Quantification of Combustion Products

- Carbon dioxide (CO_2): Collected in a suitable trap (e.g., a carbonate solution or a dry absorption tube) and quantified, often gravimetrically or by infrared spectroscopy.
- Water (H_2O): Collected in a desiccant or a condenser and quantified similarly.
- Oxygen content: Since oxygen in the original compound isn't directly measured, it is inferred by subtracting the sum of C and H from the total mass.

Data Acquisition and Typical Results

Suppose the combustion analysis yields the following data:

- Mass of CO_2 produced: X grams
- Mass of H_2O produced: Y grams

From these, the amount of carbon and hydrogen in the original sample can be calculated.

Calculations in Combustion Analysis

1. Determining Moles of Carbon and Hydrogen

- Moles of carbon:

$$
n_{C} = \frac{\text{Mass of CO}_2}{44.01\, \text{g/mol}}
$$

- Mass of carbon:

$$
m_{C} = n_{C} \times 12.01\, \text{g/mol}
$$

- Moles of hydrogen:

$$
n_{H} = \frac{\text{Mass of H}_2\text{O}}{18.02\, \text{g/mol}}
$$

- Mass of hydrogen:

$$
m_{H} = n_{H} \times 1.008\, \text{g/mol}
$$

2. Determining Mass of Oxygen in the Sample

- Total sample mass: 17.05 g
- Sum of C and H masses: $m_{C} + m_{H}$
- Mass of oxygen:

$$
m_{O} = 17.05\, \text{g} - (m_{C} + m_{H})
$$

- Moles of oxygen:

$$
n_{O} = \frac{m_{O}}{16.00\, \text{g/mol}}
$$

3. Deriving Empirical Formula

- Divide all mole quantities n_{C}, n_{H}, n_{O} by the smallest among them to find the simplest whole-number ratio.
- Round ratios to whole numbers, considering experimental uncertainties, to establish the empirical formula.

Example Calculation (Hypothetical Data)

Suppose the combustion analysis produces:

- 7.50 g of CO_2
- 2.70 g of H_2O

Calculations proceed as follows:

Carbon:

$$
n_{C} = \frac{7.50}{44.01} \approx 0.1705\, \text{mol}
$$
$$
m_{C} = 0.1705 \times 12.01 \approx 2.05\, \text{g}
$$

Hydrogen:

$$
n_{H} = \frac{2.70}{18.02} \approx 0.1498\, \text{mol}
$$
$$
m_{H} = 0.1498 \times 1.008 \approx 0.151\, \text{g}
$$

Oxygen:

$$
m_{O} = 17.05 - (2.05 + 0.151) \approx 14.85\, \text{g}
$$
$$
n_{O} = \frac{14.85}{16.00} \approx 0.928\, \text{mol}
$$

Ratios:

Divide all by the smallest number (~0.1498 mol):

$$
C: \frac{0.1705}{0.1498} \approx 1.14 \approx 1
$$
$$
H: \frac{0.1498}{0.1498} = 1
$$
$$
O: \frac{0.928}{0.1498} \approx 6.19 \approx 6
$$

Empirical formula:

$$
\boxed{\mathrm{CH_6O_6}}
$$

This simplified example illustrates the process, though actual results may vary.

Significance of the Empirical Formula

Knowing the empirical formula provides insight into the basic composition of the organic compound. It can:

- Help deduce the molecular formula when combined with molar mass data.
- Assist in structural elucidation, especially when combined with spectroscopic techniques.
- Serve as a basis for synthesizing or modifying compounds with specific elemental ratios.

Limitations and Considerations

While combustion analysis is highly effective, it has limitations:

- Incomplete combustion: Can lead to inaccurate elemental quantification.
- Volatile impurities: May skew results if not properly purified.
- Presence of heteroatoms: Elements like nitrogen or halogens require additional analysis methods, such as CHN analysis.
- Sample purity: Impurities can cause errors.
- Assumptions about oxygen: Oxygen content is inferred indirectly, which can be less accurate if other elements are present.

Advances and Complementary Techniques

Modern combustion analysis often incorporates advanced instrumentation:

- High-Temperature Combustion Analyzers: Automated systems that provide rapid and precise elemental analysis.
- Infrared and Mass Spectrometry: To confirm combustion products and detect impurities.
- Nuclear Magnetic Resonance (NMR) and Mass Spectrometry (MS): To complement elemental analysis and confirm structural hypotheses.

Conclusion

Analyzing a 17.05 g sample of an organic compound containing C, H, and O via combustion analysis exemplifies the core principles of quantitative organic analysis. Through careful experimental design, precise measurements of combustion products, and rigorous calculations, chemists can accurately determine the empirical formula, which is foundational for understanding the compound’s structure and properties.

This technique remains a cornerstone of organic chemistry, offering reliability and critical insights into molecular composition. While modern methods have enhanced the speed and accuracy of elemental analysis, combustion remains a fundamental approach, especially in initial characterization and quality control of organic materials.

Final Remarks

Understanding the intricacies of combustion analysis not only aids in elemental determination but also deepens the appreciation for the meticulous nature of chemical analysis. Whether in academic research, pharmaceutical

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development, or industrial quality assurance, mastering this technique is
essential for chemists committed to precision and scientific rigor.
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