Combustion Of 27.44 G Of A Compound Containing Only Carbon, Hydrogen, And Oxygen Produces 53.60 GCO2

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Understanding the combustion process of organic compounds is fundamental in chemistry, especially when analyzing the composition and empirical formulas of unknown substances. In this article, we explore a specific combustion scenario involving a compound containing only carbon, hydrogen, and oxygen. When 27.44 grams of this compound undergo combustion, it produces 53.60 grams of carbon dioxide (CO_2). We will analyze this data to determine the empirical formula of the compound, the amount of water produced, and the compound's molecular formula.

Introduction to Combustion Analysis

Combustion analysis is a standard method used in organic chemistry to determine the elemental composition of a compound. When a substance is burned in excess oxygen, it produces specific combustion products—primarily CO_2 and H_2O for organic compounds containing C, H, and O. By measuring the quantities of these products, chemists can back-calculate the original amounts of each element in the compound.

Key Concepts in Combustion Analysis:
- Complete combustion results in products that reflect the original elements.
- The amount of CO_2 indicates the carbon content.
- The amount of H_2O indicates the hydrogen content.
- The remaining oxygen in the original compound is calculated based on the difference.

Calculating the Carbon Content from CO_2 Production

Since the compound contains only carbon, hydrogen, and oxygen, the first step is to determine how much carbon was present in the original 27.44 g sample based on the amount of CO_2 produced.

Step 1: Moles of CO_2 Produced

The molar mass of CO_2 is:

- Carbon (C): 12.01 g/mol
- Oxygen (O): 16.00 g/mol

$$
\text{Molar mass of CO}_2 = 12.01 + 2 \times 16.00 = 44.01 \text{ g/mol}
$$

Number of moles of CO_2 produced:

$$
n_{CO_2} = \frac{\text{Mass of CO}_2}{44.01} = \frac{53.60 \text{ g}}{44.01 \text{ g/mol}} \approx 1.218 \text{ mol}
$$

Step 2: Moles of Carbon in the Sample

Since each mole of CO_2 contains one mole of carbon:

$$
n_C = n_{CO_2} \approx 1.218 \text{ mol}
$$

Mass of carbon in the original sample:

$$
m_C = n_C \times 12.01 \text{ g/mol} \approx 1.218 \times 12.01 \approx 14.63 \text{ g}
$$

Result: The sample contains approximately 14.63 grams of carbon.

Calculating the Hydrogen Content from Water Production

Next, we determine the amount of hydrogen in the original compound based on water produced during combustion.

Step 1: Assume Water Production Data

Suppose we know or can find the mass of water produced; in typical problems of this nature, it is often given or calculated indirectly. Since the total mass of the compound is 27.44 g, and total carbon is 14.63 g, the remaining mass is attributed to hydrogen and oxygen.

The total mass of the original compound:

$$
27.44 \text{ g}
$$

Mass of oxygen in the original compound:

$$
m_O = 27.44 - (m_C + m_{H,\text{initial}})
$$

But we need to find m_H first.

Alternative approach: Typically, in combustion analysis, the amount of water produced is measured directly. If water mass is not given, we can determine it by subtracting the mass of carbon and oxygen in the original compound.

Determining the Oxygen Content in the Original Compound

Since the compound contains only C, H, and O, their total masses sum to 27.44 g:

$$
m_C + m_H + m_O = 27.44 \text{ g}
$$

We already have $m_C \approx 14.63 \text{ g}$. To find m_O and m_H, we need to analyze the total oxygen content.

Calculating the Oxygen and Hydrogen Contents

Step 1: Total Oxygen in the Compound

The oxygen in the original compound is not accounted for in the combustion products directly, but the oxygen in CO_2 and H_2O contributes to the total oxygen content in the combustion products.

- Moles of CO_2: 1.218 mol
- Moles of H_2O: Let's denote as n_{H_2O}

The mass of oxygen in CO_2:

$$
m_{O,CO_2} = n_{CO_2} \times 2 \times 16.00 = 1.218 \times 32.00 \approx 38.98 \text{ g}
$$

Similarly, the mass of water produced:

$$
m_{H_2O} = n_{H_2O} \times 18.02
$$

But since the total mass of water is unknown, we need more data or assumptions.

Using the Data to Find the Empirical Formula

Given the data, we can proceed to determine the empirical formula of the compound.

Step 1: Calculate moles of Carbon

$$
n_C \approx 1.218 \text{ mol}
$$

Step 2: Calculate moles of Hydrogen

Assuming the mass of hydrogen in the original compound is m_H, then:

$$
n_H = \frac{m_H}{1.008} \text{ mol}
$$

But without the precise amount of water produced, we can use an alternative approach.

Alternative Approach: Using Elemental Composition to Find Empirical Formula

Since the problem provides the initial mass of the compound and the mass of CO_2, the amount of carbon is known. To find hydrogen and oxygen, we'll use the following steps:

1. Mass of Carbon (already calculated): approximately 14.63 g
2. Mass of remaining elements (H and O):

$$
m_{H+O} = 27.44 - 14.63 = 12.81 \text{ g}
$$

3. Express the remaining mass as contributions of H and O:

$$
m_H + m_O = 12.81 \text{ g}
$$

4. Relate the hydrogen to water produced:

- Each mole of H_2O contains 2 moles of H, so:

$$
n_H = 2 \times n_{H_2O}
$$

- Mass of water produced:

$$
m_{H_2O} = n_{H_2O} \times 18.02
$$

- Mass of hydrogen:

$$
m_H = n_H \times 1.008 = 2 \times n_{H_2O} \times 1.008 = 2.016 \times n_{H_2O}
$$

- But since the total hydrogen mass in the compound is:

$$
m_H = \text{mass of hydrogen in original sample}
$$

we need the value of m_H or n_{H_2O} to proceed.

Estimating the Empirical Formula

Given the limitations and typical data in such problems, a common approach is to assume the hydrogen content based on typical ratios or by using the combustion data.

Assuming complete combustion:

- The amount of hydrogen in the original compound is:

$$
m_H = \text{mass of hydrogen in the sample}
$$

- Total oxygen in the original compound is:

$$
m_O = 27.44 - (m_C + m_H)
$$

If we assume the compound has a typical ratio, or if additional data is provided, the empirical formula can be derived.

Conclusion: Determining the Empirical and Molecular Formula

Based on the data:

- Carbon content: approximately 14.63 g
- Total initial mass: 27.44 g
- Remaining mass (H + O): approximately 12.81 g

If the hydrogen content can be estimated from known combustion reactions or experimental data, the empirical formula typically follows these steps:

1. Convert masses to moles.
2. Divide by the smallest number of moles to find mole ratios.
3. Express ratios as whole numbers to obtain empirical formula.

For example:

- If the hydrogen content corresponds to approximately 2 g, then:

$$
n_H = \frac{2}{1.008} \approx 1.984 \text{ mol}
$$

- The oxygen content:

$$
m_O = 12.81 - 2 \approx 10.81 \text{ g}
$$

$$
n_O = \frac{10.81}{16.00} \approx 0.676 \text{ mol}
$$

- Moles ratio:

$$
C: 1.218 \text{ mol}
$$

\[
H: 1.984

Frequently Asked Questions

What is the primary goal when analyzing the combustion of a compound containing only carbon, hydrogen, and oxygen?

The primary goal is to determine the compound's empirical or molecular formula by analyzing the amounts of CO_2 and H_2O produced during combustion.

Given 27.44 g of the compound produces 53.60 g of CO_2, how can we find the amount of carbon in the original compound?

First, calculate the moles of CO_2 produced by dividing 53.60 g by its molar mass (44.01 g/mol), then multiply by 1 mol C per mol CO_2 to find the moles of carbon, and convert to grams.

How does the mass of CO_2 produced relate to the amount of carbon in the compound?

Since each mole of CO_2 contains one mole of carbon, the mass of carbon in the original compound can be directly derived from the moles of CO_2 produced during combustion.

What additional data is needed to determine the empirical formula of the compound?

The mass of water produced during combustion is needed to calculate the moles of hydrogen, and the remaining mass after accounting for carbon and hydrogen can be attributed to oxygen.

How can we find the amount of oxygen in the compound based on the combustion data?

After calculating the masses of carbon and hydrogen, subtract their combined mass from the original mass of the compound to find the mass of oxygen.

Why is it important to determine the empirical formula of the compound in combustion analysis?

Determining the empirical formula helps understand the compound's composition, which is essential for identifying the compound or deriving its molecular formula.

What assumptions are made in calculating the composition of the compound from combustion data?

Assumptions include complete combustion, no other products besides CO_2 and H_2O, and that all carbon and hydrogen are converted to gaseous products without loss.

How can the molar mass of the compound be estimated from combustion data?

By determining the empirical formula and its molar mass, and if the molar mass of the compound is known or can be inferred from molecular weight data, it can be used to find the molecular formula.

What are typical steps to analyze combustion data for a compound containing only C, H, and O?

Steps include calculating moles of CO_2 and H_2O produced, determining grams of C and H, calculating the remaining oxygen, establishing the empirical formula, and then deriving the molecular formula if molar mass is known.

Additional Resources

Combustion Analysis of a Carbon-Hydrogen-Oxygen Compound: Unveiling the Molecular Composition from Experimental Data

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Introduction

In the realm of organic chemistry and analytical chemistry, combustion analysis remains a fundamental method for elucidating the empirical formulas of unknown compounds. The problem at hand involves a compound composed solely of carbon (C), hydrogen (H), and oxygen (O), with a known mass of 27.44 grams that, upon complete combustion, produces 53.60 grams of carbon dioxide (CO_2). This scenario is a classic example used to illustrate the principles of stoichiometry, molecular weight determination, and empirical formula calculation.

This article offers a comprehensive exploration of how to interpret such data, the underlying chemical principles, and the step-by-step process to deduce the compound's composition. We will delve into the theoretical foundations, calculations, and implications, making this a valuable resource for students, educators, and professionals interested in analytical techniques and organic compound characterization.

Understanding the Combustion Process

What is Combustion Analysis?

Combustion analysis involves burning a known mass of a sample in excess oxygen to produce combustion products, primarily CO_2 and H_2O for hydrocarbons and oxygenated compounds. By measuring the amounts of these products, one can back-calculate the amounts of carbon, hydrogen, and oxygen originally present in the sample.

The Significance of Complete Combustion

Complete combustion ensures that all the carbon in the original sample is converted into CO_2, and all hydrogen is converted into water (H_2O). For compounds containing only C, H, and O, the combustion products are straightforward to analyze because:

- Carbon content is inferred from CO_2 production.
- Hydrogen content is inferred from H_2O production (not provided in this problem but generally part of full analysis).
- Oxygen content is deduced indirectly since it is neither produced nor consumed during combustion but is part of the original compound.

Analyzing the Experimental Data

Let's restate the key data:

- Mass of compound (sample): 27.44 g
- Mass of CO_2 produced: 53.60 g

From this data, our goal is to determine the empirical formula of the compound, i.e., the relative molar ratios of C, H, and O.

Step 1: Calculating the Moles of Carbon from CO_2

The first step involves converting the mass of CO_2 produced into moles of carbon.

Molecular weight of CO_2: 44.01 g/mol

Number of moles of CO_2:

$$
n_{\mathrm{CO_2}} = \frac{\text{Mass of CO}_2}{\text{Molecular weight of CO}_2} = \frac{53.60\, \text{g}}{44.01\, \text{g/mol}} \approx 1.218\, \text{mol}
$$

Since each mole of CO_2 contains 1 mol of carbon:

$$
\text{Moles of C} = n_{\mathrm{CO_2}} \approx 1.218\, \text{mol}
$$

Mass of carbon in the original compound:

$$
\text{Mass of C} = \text{moles of C} \times \text{molar mass of C} = 1.218\, \text{mol} \times 12.01\, \text{g/mol} \approx 14.63\, \text{g}
$$

Step 2: Calculating the Hydrogen Content

Hydrogen analysis typically involves measuring water produced during combustion; however, since water data isn't provided, we infer hydrogen content through alternative approaches.

Assumption: The total combustion products include only CO_2 and H_2O, and the initial sample contains only C, H, and O.

If the amount of hydrogen were known, the calculation would be straightforward. But in this case, we can proceed to deduce the oxygen content by difference once we analyze the sample's total mass and the carbon content.

Step 3: Determining the Oxygen Content

The total mass of the original compound is 27.44 g, and the masses of carbon and hydrogen are related to the combustion products. Since we have the mass of carbon:

$$
\text{Mass of remaining elements (H and O)} = 27.44\, \text{g} - 14.63\, \text{g} = 12.81\, \text{g}
$$

To find the hydrogen mass, we need additional data—specifically, the amount of water produced during combustion or a similar measurement.

Note: In many standard combustion analyses, the amount of water produced is measured. For this problem, assuming only the data provided, we can infer the hydrogen content if we consider typical combustion behavior or via a hypothetical value.

However, given the problem's setup, it's more typical to proceed with an assumption or an additional given value for the mass of water produced.

Clarification: Inferring Hydrogen from the Data

Given the data, it is clear that the problem expects us to determine the empirical formula solely based on the carbon dioxide produced and the known total mass, which suggests that the hydrogen content might be inferred or provided elsewhere.

Suppose that the total combustion products have only CO_2 and H_2O, and the total mass of combustion products is 53.60 g of CO_2. The total initial mass was 27.44 g, and the amount of carbon is 14.63 g, leaving the rest for hydrogen and oxygen.

Alternatively, the problem may assume that the entire combustion process produces only CO_2, implying the compound is a hydrocarbon or similar, with oxygen content determined indirectly.

Step 4: Calculating the Oxygen Content

Since the compound contains only C, H, and O, and the total mass is known, the oxygen mass can be calculated as:

$$
\text{Mass of O} = \text{Total mass} - \text{Mass of C} - \text{Mass of H}
$$

But as H isn't given explicitly, the problem likely expects us to proceed with the assumption that the total mass of gases produced and the initial mass can lead us to the empirical formula.

An Alternative Approach: Empirical Formula Derivation

Given the data, here's a step-by-step method:

1. Calculate the moles of carbon (done above): approximately 1.218 mol.

2. Estimate hydrogen:

- Since the problem involves only C, H, and O, and the total combustion products are only CO_2, the key is to find the hydrogen content from the combustion data involving water, which is absent here.

3. Estimate oxygen content:

- The total mass of the compound is 27.44 g.
- The mass of carbon is 14.63 g.
- The remaining mass (27.44 - 14.63) = 12.81 g includes hydrogen and oxygen.

Final Step: Deducing the Empirical Formula

Given the standard approach, the most logical conclusion is that the problem is designed to test the ability to calculate the empirical formula from the carbon dioxide produced and total mass, assuming the rest of the data or typical combustion analysis.

Assuming the compound is a hydrocarbon (C_xH_y), but with oxygen, the general empirical formula is:

$$
\mathrm{C}_x \mathrm{H}_y \mathrm{O}_z
$$

Detailed Calculation Process

Let's now formalize the calculations, assuming the missing data (mass of water produced) is provided or can be inferred.

Suppose the combustion produces 53.60 g of CO_2, and the total combustion products include a certain amount of H_2O (say, as part of the full data set). For simplicity, let's assume the problem intends for us to focus on the carbon content and the total mass to find the empirical formula.

Given the data:

- Mass of sample = 27.44 g
- Mass of CO_2 produced = 53.60 g

The data suggests that the carbon in the original sample accounts for approximately 14.63 g as calculated.

Calculating the percentage of carbon in the original compound:

$$
\%\text{C} = \frac{14.63\, \text{g}}{27.44\, \text{g}} \times 100 \approx 53.3\%
$$

Similarly, if we had the water data, we could find hydrogen percentage; otherwise, we proceed with typical assumptions.

Interpretation of Results

The key insight from the combustion data is that approximately 53.3% of the compound's mass is carbon. The remaining ~46.7% is composed of hydrogen and oxygen.

If experimental data for water production is available, similar calculations can be performed to find hydrogen content. But in the absence of such data, the critical takeaway is that the compound contains a significant amount of carbon, roughly half of its mass.

Conclusion: What Does the Data Reveal?

This combustion analysis exemplifies how experimental data can unlock the molecular composition of an unknown compound. By analyzing the mass of CO_2 produced, we deduce the amount of carbon present. Subsequently, subtracting this from the total mass allows for estimating hydrogen and oxygen content, which then facilitates deriving an empirical formula.

In this case, the data indicates:

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- Approximate carbon content: 14.63 g
- Total sample mass: 27.44 g
- Estimated empirical formula: likely a hydro
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