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Understanding the relationship between the mass of a compound and its elemental composition is fundamental in chemistry. When lead oxide is reduced to metallic lead, the mass difference provides vital clues about its chemical formula. This article guides you through the step-by-step process of calculating the empirical formula of the oxide of lead based on the given data: 6.75 grams of lead oxide reduced to 6.12 grams of metallic lead. This involves concepts like mass conservation, molar calculations, and determining empirical formulas, which are essential skills for students and professionals in chemistry.

Introduction to Lead Oxide and Its Reduction

Lead oxide, commonly represented as PbO, is a compound composed of lead and oxygen atoms. It exists in different forms, such as litharge (yellow PbO) and massicot (red PbO). The reduction process involves removing oxygen from lead oxide, typically using a reducing agent like carbon, to produce metallic lead.

The key observation here is that when lead oxide (PbO) is reduced, part of its mass is lost as oxygen gas (O_2), leaving behind metallic lead. We are given the initial mass of the oxide and the final mass of the lead metal after reduction:

- Initial mass of PbO: 6.75 g
- Final mass of metallic Pb: 6.12 g

From this data, our goal is to determine the empirical formula of the oxide, which indicates the simplest whole-number ratio of lead to oxygen atoms in the compound.

Understanding the Data and Its Significance

Before diving into calculations, it is essential to interpret the data correctly:

- The difference in mass (initial minus final) indicates the amount of oxygen that was removed during reduction.
- Mass of oxygen lost = 6.75 g (initial) - 6.12 g (metallic lead remaining) = 0.63 g

This tells us how much oxygen was originally present in the oxide.

Key Points to Note

1. The reduction process involves oxygen removal, so the mass difference corresponds to oxygen mass.

2. The remaining mass (6.12 g) is purely lead in metallic form.

3. The empirical formula depends on the ratio of moles of lead to oxygen in the compound.

Step-by-Step Calculation Process

To determine the empirical formula, follow these systematic steps:

1. Calculate the number of moles of lead in the final metal

The molar mass of lead (Pb) = 207.2 g/mol

Number of moles of lead:

$$ \text{Moles of Pb} = \frac{\text{Mass of Pb}}{\text{Molar mass of Pb}} = \frac{6.12\, \text{g}}{207.2\, \text{g/mol}} $$

$$ \approx 0.0296\, \text{mol} $$

2. Calculate the number of moles of oxygen in the original oxide

Mass of oxygen lost during reduction:

$$ 0.63\, \text{g} $$

Molar mass of oxygen (O) = 16.0 g/mol

Number of moles of oxygen:

$$ \text{Moles of O} = \frac{0.63\, \text{g}}{16.0\, \text{g/mol}} $$

$$ \approx 0.0394\, \text{mol} $$

3. Determine the mole ratio of lead to oxygen

Calculate the simplest whole-number ratio:

\[
\frac{\text{Moles of Pb}}{\text{Moles of O}} = \frac{0.0296}{0.0394} \approx

$$
0.75
$$

To express this as whole numbers, divide both by the smaller value:

$$
\text{Ratio of Pb} : \text{O} \approx 0.75 : 1
$$

Multiplying both by 4 to clear fractions:

$$
0.75 \times 4 = 3 \quad \text{and} \quad 1 \times 4 = 4
$$

Thus, the mole ratio of lead to oxygen is approximately 3:4.

4. Write the empirical formula based on the ratio

The ratio indicates that in the simplest whole-number terms:

- 3 atoms of lead (Pb)
- 4 atoms of oxygen (O)

Therefore, the empirical formula of the oxide is:

$$ \text{Pb}_3\text{O}_4 $$

Verifying the Empirical Formula

To ensure the calculation's accuracy, verify whether the molar masses align with experimental data:

- Molar mass of Pb_3O_4:

$$ (3 \times 207.2) + (4 \times 16.0) = 621.6 + 64 = 685.6\, \text{g/mol} $$

- Mass ratio in the compound:

$$
\frac{\text{Mass of Pb in formula}}{\text{Mass of Pb}_3\text{O}_4} = \frac{3 \times 207.2}{685.6} \approx 0.906
$$

- Calculated mass of oxygen:

$$
4 \times 16.0 = 64\, \text{g}
$$

- Total mass per mole:

$$
685.6\, \text{g}
$$

- Percentage of oxygen:

$$
\frac{64}{685.6} \times 100\% \approx 9.33\%
$$

Considering the original mass of 6.75 g, with 0.63 g of oxygen, the percentage of oxygen in the compound:

$$
\frac{0.63\, \text{g}}{6.75\, \text{g}} \times 100\% \approx 9.33\%
$$

This matches the theoretical percentage, confirming the empirical formula.

Additional Considerations

While this calculation indicates the empirical formula is Pb_3O_4, it is noteworthy that:

- Lead(II,IV) oxide, Pb_3O_4, is a known compound, often called red lead.
- The empirical formula aligns with the known composition of Pb_3O_4, which has a mixed oxidation state for lead (Pb^{2+} and Pb^{4+}).

Implications in Chemistry and Industry

- **Historical significance**: Pb_3O_4 has been used as a pigment and in lead-based batteries.
- **Environmental impact**: Understanding lead compounds is crucial due to toxicity concerns.
- **Analytical importance**: Calculations like these demonstrate the importance of stoichiometry in identifying compounds.

Summary and Conclusion

In summary, by analyzing the initial and final masses, calculating moles of lead and oxygen, and determining their ratio, we deduced that the empirical formula of the oxide of lead in this scenario is Pb_3O_4. This process exemplifies fundamental principles in chemistry such as mass conservation, molar calculations, and empirical formula determination.

Key takeaways include:

- The importance of precise data interpretation.
- The methodical approach to stoichiometric calculations.
- The significance of empirical formulas in understanding compound composition.

Mastering such calculations is essential for students and professionals involved in inorganic chemistry, materials science, and chemical analysis. Whether you're analyzing ores, developing new compounds, or conducting research, understanding how to derive empirical formulas from experimental data is a vital skill.

FAQs

Q1: Why is it important to find the empirical formula of a compound?

> It provides the simplest whole-number ratio of elements in a compound, essential for understanding its composition and for further structural analysis.

Q2: Can the empirical formula differ from the molecular formula?

> Yes. The empirical formula shows the simplest ratio, while the molecular formula indicates the actual number of atoms in a molecule, which may be a multiple of the empirical formula.

Q3: Why is molar mass essential in these calculations?

> It allows conversion between mass and moles, which is necessary for establishing ratios between different elements in compounds.

End of the comprehensive guide on calculating the empirical formula of lead oxide based on reduction data.

Frequently Asked Questions

What is the first step in determining the empirical formula of lead oxide given its reduction data?

The first step is to find the amount of oxygen removed during reduction by subtracting the mass of the metal from the initial oxide mass.

How do you calculate the mass of oxygen in the lead oxide sample?

Subtract the mass of the metal (6.12 g) from the initial oxide mass (6.75 g), which gives 0.63 g of oxygen.

What is the molar mass of lead (Pb) and oxygen (O)?

The molar mass of lead (Pb) is approximately 207 g/mol, and oxygen (O) is approximately 16 g/mol.

How do you find the mole ratio of lead to oxygen in the compound?

Divide the mass of each element by its molar mass to find the number of moles, then divide both by the smallest number of moles to get the simplest ratio.

What is the empirical formula of the lead oxide based on the calculations?

The empirical formula is PbO, as the mole ratio of Pb to O is approximately 1:1.

Why is determining the empirical formula of lead oxide important in chemistry?

It helps in understanding the composition and stoichiometry of the compound, which is essential for reactions, manufacturing, and material properties.

Additional Resources

Understanding the Empirical Formula of Oxide of Lead From Reduction Data

When exploring chemical compounds, especially oxides, determining their empirical formulas is fundamental to understanding their composition and properties. The process involves analyzing experimental data—here, the reduction of lead oxide—and applying stoichiometry principles to deduce the simplest whole-number ratio of elements within the compound. In this detailed discussion, we will examine how to calculate the empirical formula of lead oxide based on the given data: starting from 6.75 grams of the oxide and reducing it to 6.12 grams of metallic lead.

Introduction to Lead Oxide and Its Significance

Lead oxides are significant in various industrial applications, including batteries, glass manufacturing, and as pigments. The most common forms are:

- Lead(II) oxide (PbO), also known as litharge.
- Lead(IV) oxide (PbO_2), known as lead dioxide.

Understanding the empirical formula involves identifying the ratio of lead to oxygen atoms in the compound. The reduction process provides essential clues because it involves the conversion of lead oxide to metallic lead, during which oxygen is removed.

Understanding the Data and Its Implications

The problem provides specific data:

- Initial mass of lead oxide (Pb_xO_y): 6.75 grams
- Mass of lead obtained after reduction: 6.12 grams

From this, we infer:

- The amount of oxygen removed during reduction can be calculated by the difference in mass:

Oxygen removed = 6.75 g - 6.12 g = 0.63 g

The reduction process suggests:

- The lead oxide was reduced to elemental lead.
- The oxygen was released as a gaseous form (likely as O_2).

Step-by-Step Calculation Process

To determine the empirical formula, we follow a systematic approach:

1. Calculate the mass of lead in the oxide

The mass of lead in the original compound is:

- Mass of lead (Pb): 6.12 g (since the reduction yields metallic lead)

2. Calculate the mass of oxygen in the oxide

- Mass of oxygen (O): 0.63 g (as calculated above)

3. Convert masses to moles

Using atomic masses:

- Lead (Pb): approximately 207.2 g/mol
- Oxygen (O): approximately 16.0 g/mol

Calculations:

- Moles of lead:

$$
\text{Moles of Pb} = \frac{6.12\,g}{207.2\,g/mol} \approx 0.02956\, \text{mol}
$$

- Moles of oxygen:

$$
\text{Moles of O} = \frac{0.63\,g}{16.0\,g/mol} \approx 0.03938\, \text{mol}
$$

4. Determine the molar ratio

To find the simplest whole number ratio, divide both by the smaller number of moles:

- Ratio of Pb:

$$
\frac{0.02956}{0.02956} = 1
$$

- Ratio of O:

$$
\frac{0.03938}{0.02956} \approx 1.33
$$

5. Adjust ratios to whole numbers

Since 1.33 is not a whole number, multiply both ratios by a common factor to clear the decimal:

- Multiply both by 3:

$$
\text{Pb}: 1 \times 3 = 3
$$

$$
\text{O}: 1.33 \times 3 \approx 4
$$

Thus, the empirical formula is Pb_3O_4.

Interpreting the Empirical Formula

The derived ratio suggests that the compound has 3 lead atoms to 4 oxygen atoms per formula unit, which corresponds to lead(II,IV) oxide (Pb_3O_4), a mixed-valence oxide. This compound is well-known and exhibits unique properties due to the coexistence of Pb(II) and Pb(IV).

Key points:

- Pb_3O_4 is a stable compound with a mixed oxidation state.
- It is commonly called red lead or minium.
- The empirical formula matches the stoichiometry seen in the reduction data.

Broader Implications and Validation of Results

Validity of Calculations:

- The calculation aligns with known chemical data for lead oxides.
- The molar ratios are consistent with literature: Pb_3O_4 contains 3 Pb atoms and 4 O atoms.
- The reduction data supports this, as the oxygen mass and lead mass correlate directly to the formula.

Additional Considerations:

- If the original compound was purely PbO, the ratio would be 1:1; the data suggests a more complex oxide.
- The experimental data indicates that the oxide is not simply PbO, but a higher oxide (Pb_3O_4).

Understanding Oxidation States and Chemical Behavior

Knowing the empirical formula provides insight into the oxidation states:

- In PbO, lead is +2.
- In PbO_2, lead is +4.
- In Pb_3O_4, lead exists as a mixture of +2 and +4 oxidation states.

This mixed-valence nature influences:

- The compound's color (red in the case of Pb_3O_4).
- Its chemical reactivity and stability.
- Its electrical properties, notably in battery applications.

Summary of the Calculation Process

To sum up:

- Starting with initial data, calculated the amount of oxygen removed.
- Converted masses to moles using atomic weights.
- Determined the molar ratio of lead to oxygen.
- Simplified the ratio to whole numbers.
- Recognized the empirical formula as Pb_3O_4.

This process exemplifies how stoichiometry and empirical formula determination are fundamental skills in inorganic chemistry.

Additional Insights and Practical Applications

Understanding how to derive empirical formulas from reduction data has practical significance:

- Quality Control: Ensuring the correct composition of lead oxides used in manufacturing.
- Material Characterization: Confirming the structure of synthesized compounds.
- Environmental Chemistry: Assessing the oxidation states of lead in environmental samples.

Moreover, this calculation underscores the importance of precise measurements and careful calculations, as small errors can lead to incorrect interpretations of the compound's formula.

Conclusion

The detailed analysis of the reduction data reveals that the empirical formula of the lead oxide in question is Pb_3O_4. This compound's structure and properties are deeply tied to its mixed oxidation states, which are consistent with the molar ratios derived from experimental data.

Understanding these concepts allows chemists to interpret experimental results accurately, predict chemical behavior, and synthesize materials with desired properties. The process demonstrated here exemplifies how fundamental stoichiometry and analytical reasoning underpin much of inorganic chemistry.

Final Note: Always remember that empirical formulas are the simplest whole-number ratios of elements in a compound. The process described here applies broadly to various compounds and reduction data, serving as a cornerstone technique in chemical analysis.

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