A Sample Of 1.50 G Of Lead(II) Nitrate Is Mixed With 120 ML Of 0.109 M Sodium Sulfate Solution.A.) What

A Sample Of 1.50 G Of Lead(II) Nitrate Is Mixed With 120 ML Of 0.109 M Sodium Sulfate Solution.A.) What happens during this chemical reaction? Understanding this process requires delving into the fundamentals of double displacement reactions, solubility rules, and stoichiometry. This scenario provides an excellent opportunity to explore how ionic compounds interact in aqueous solutions, what precipitate forms, and how to calculate the theoretical yield of the reaction products. Whether you're a student studying chemistry or an enthusiast interested in chemical reactions, this article will guide you through the intricate details of what transpires when lead(II) nitrate is mixed with sodium sulfate.

Understanding the Reactants

Lead(II) Nitrate ($Pb(NO_3)_2$)

Lead(II) nitrate is an inorganic compound composed of lead, nitrogen, and oxygen. Its chemical formula is $Pb(NO_3)_2$, indicating that each molecule contains one lead ion (Pb^{2+}) and two nitrate ions (NO_3^-). It is highly soluble in water, meaning it readily dissociates into its constituent ions:
- $Pb(NO_3)_2$ (aq) → Pb^{2+} (aq) + 2 NO_3^- (aq)

Sodium Sulfate (Na_2SO_4)

Sodium sulfate is an inorganic salt with the chemical formula Na_2SO_4. It is also soluble in water and dissociates into sodium and sulfate ions:
- Na_2SO_4 (aq) → 2 Na^+ (aq) + SO_4^{2-} (aq)

Understanding the behavior of these ions in solution is crucial because the reaction depends on their interactions.

Reaction Overview and Equation

Double Displacement Reaction

When solutions containing Pb^{2+} and SO_4^{2-} ions are mixed, a double displacement (metathesis) reaction occurs. The lead(II) sulfate ($PbSO_4$) formed is insoluble in water, leading to its precipitation, while sodium nitrate remains dissolved.

The balanced chemical equation is:

- $Pb(NO_3)_2$ (aq) + Na_2SO_4 (aq) → $PbSO_4$ (s) + 2 $NaNO_3$ (aq)

This reaction exemplifies a classic precipitation reaction, where an insoluble salt forms from the mixing of two soluble salts.

Calculating the Moles of Reactants

Lead(II) Nitrate

Given:
- Mass of $Pb(NO_3)_2$ = 1.50 g
- Molar mass of $Pb(NO_3)_2$ = 331.2 g/mol

Calculations:
- Moles of $Pb(NO_3)_2$ = 1.50 g / 331.2 g/mol ≈ 0.00453 mol

Sodium Sulfate Solution

Given:
- Volume = 120 mL = 0.120 L
- Molarity = 0.109 M

Calculations:
- Moles of Na_2SO_4 = 0.109 mol/L × 0.120 L ≈ 0.01308 mol

Comparing the molar amounts helps determine which reactant is the limiting reagent.

Determining the Limiting Reagent

Since the reaction requires 1 mol of $Pb(NO_3)_2$ to react with 1 mol of Na_2SO_4, we compare the available moles:

- $Pb(NO_3)_2$ available: 0.00453 mol
- Na_2SO_4 available: 0.01308 mol

Because 0.00453 mol of $Pb(NO_3)_2$ requires 0.00453 mol of Na_2SO_4, and we have more Na_2SO_4 than that (0.01308 mol), lead(II) nitrate is the limiting reagent.

Conclusion: The amount of precipitate formed will depend on the amount of $Pb(NO_3)_2$ present.

Calculating the Mass of Lead(II) Sulfate ($PbSO_4$)

Precipitate

Stoichiometry of the Reaction

From the balanced equation:
- 1 mol of $Pb(NO_3)_2$ produces 1 mol of $PbSO_4$

Since $Pb(NO_3)_2$ is limiting:
- Moles of $PbSO_4$ formed = 0.00453 mol

Molar Mass of $PbSO_4$

- Pb (207.2 g/mol)
- S (32.07 g/mol)
- 4 O (4 × 16.00 g/mol = 64.00 g/mol)

Total:
- Molar mass of $PbSO_4$ = 207.2 + 32.07 + 64.00 ≈ 303.27 g/mol

Mass of $PbSO_4$ Precipitate

- Mass = moles × molar mass = 0.00453 mol × 303.27 g/mol ≈ 1.37 g

Result: Approximately 1.37 g of lead(II) sulfate will precipitate from the reaction.

Additional Considerations

Remaining Ions in Solution

The excess sodium sulfate remains in solution as sodium and sulfate ions. The solution will contain:
- 2 × 0.01308 mol = 0.02616 mol of Na^+
- 0.01308 mol of SO_4^{2-} (minus the amount reacted, but since all sulfate ions are in excess, most remain unreacted)

Implications for Purity and Applications

Lead(II) sulfate is used in various applications, including in paints, plastics, and as a radiocontrast agent. However, due to lead's toxicity, handling and disposal must adhere to safety regulations.

Summary of Key Calculations

1. Calculate moles of lead(II) nitrate: 0.00453 mol
2. Calculate moles of sodium sulfate: 0.01308 mol
3. Identify limiting reagent: $Pb(NO_3)_2$
4. Determine precipitate mass: approximately 1.37 g of $PbSO_4$

Conclusion

Mixing 1.50 g of lead(II) nitrate with 120 mL of 0.109 M sodium sulfate solution results in a precipitation reaction where roughly 1.37 g of lead(II) sulfate is formed. This reaction demonstrates the principles of solubility, stoichiometry, and limiting reagents in inorganic chemistry. Understanding such reactions is essential for chemists involved in synthesis, quality control, and environmental chemistry, especially considering the toxicity of lead compounds.

In essence, this example encapsulates fundamental concepts in analytical and inorganic chemistry, illustrating how to predict reaction outcomes, perform stoichiometric calculations, and interpret the results in real-world contexts.

Frequently Asked Questions

What is the balanced chemical equation for the reaction between Lead(II) nitrate and Sodium sulfate?

The balanced chemical equation is: $Pb(NO_3)_2 + Na_2SO_4 \rightarrow PbSO_4\ (s) + 2\ NaNO_3$.

What is the molar mass of Lead(II) nitrate ($Pb(NO_3)_2$)?

The molar mass of $Pb(NO_3)_2$ is approximately 331.2 g/mol.

How many moles of Lead(II) nitrate are present in 1.50 g?

Number of moles = 1.50 g / 331.2 g/mol ≈ 0.00453 mol.

What is the number of moles of Sodium sulfate in 120 mL of 0.109 M solution?

Moles of Na_2SO_4 = 0.109 mol/L × 0.120 L = 0.01308 mol.

Will a precipitate of Lead(II) sulfate form in this reaction?

Yes, because the concentration of sulfate ions exceeds the solubility product, leading to the formation of $PbSO_4$ precipitate.

How many grams of Lead(II) sulfate will precipitate from the reaction?

Moles of $PbSO_4$ formed are limited by the limiting reagent—calculate based on molar ratios; approximately 0.00453 mol of $PbSO_4$ will precipitate, which equals about 1.07 g (using molar mass of ~319.2 g/mol).

What is the limiting reagent in this reaction?

Lead(II) nitrate is the limiting reagent because there are fewer moles compared to sodium sulfate.

What are the practical applications of lead sulfate precipitates in industry?

Lead sulfate is used in lead-acid batteries, as a pigment in paints, and in other industrial processes, but handling requires care due to its toxicity.

Additional Resources

Understanding the Reaction Between Lead(II) Nitrate and Sodium Sulfate: A Detailed Chemical Analysis

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Introduction

In the realm of inorganic chemistry, reactions involving soluble salts often lead to fascinating precipitation phenomena, particularly when dealing with metal cations and sulfate ions. One such classic example is the interaction between lead(II) nitrate ($Pb(NO_3)_2$) and sodium sulfate (Na_2SO_4). This reaction exemplifies a double displacement (metathesis) process, resulting in the formation of an insoluble lead(II) sulfate ($PbSO_4$) precipitate and the formation of sodium nitrate ($NaNO_3$) in solution.

This comprehensive review will dissect the scenario where a sample containing 1.50 grams of lead(II) nitrate is mixed with 120 mL of 0.109 M sodium sulfate solution. We will explore the fundamental concepts, calculations, and implications step by step, covering solubility considerations, reaction stoichiometry, and practical applications.

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1. Chemical Background and Significance

Lead(II) Nitrate ($Pb(NO_3)_2$):
An inorganic salt highly soluble in water, providing lead(II) ions (Pb^{2+}) and nitrate ions (NO_3^-). It's

often employed in chemical syntheses, analytical chemistry, and as a precursor for lead-based compounds.

Sodium Sulfate (Na_2SO_4):
A stable, highly soluble sodium salt that supplies sulfate ions (SO_4^{2-}). Its aqueous solutions are commonly used in various chemical reactions, including precipitation reactions.

Precipitation Reaction:
When solutions of $Pb(NO_3)_2$ and Na_2SO_4 are mixed, the common ion exchange leads to the formation of lead(II) sulfate, a sparingly soluble salt, which precipitates out of solution, enabling separation and qualitative analysis.

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2. Fundamental Concepts

a. Solubility Product (Ksp):

The solubility of $PbSO_4$ is governed by its Ksp value, which indicates its degree of solubility in water at a given temperature:

$$
\text{PbSO}_4 (s) \leftrightarrow \text{Pb}^{2+} (aq) + \text{SO}_4^{2-} (aq)
$$

Ksp for $PbSO_4$ at 25°C is approximately 1.6×10^{-8}.

This low value signifies that $PbSO_4$ is only sparingly soluble, and precipitation occurs when the ionic product exceeds the Ksp.

b. Stoichiometry of the Reaction:

The balanced chemical equation:

$$
\text{Pb(NO}_3)_2 (aq) + \text{Na}_2\text{SO}_4 (aq) \rightarrow \text{PbSO}_4 (s) + 2 \text{NaNO}_3 (aq)
$$

- One mole of lead(II) nitrate reacts with one mole of sodium sulfate to produce one mole of lead(II) sulfate precipitate and two moles of sodium nitrate.

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3. Calculations and Analysis

a. Calculating Moles of Lead(II) Nitrate

Given:
- mass of $Pb(NO_3)_2$ = 1.50 g
- molar mass of $Pb(NO_3)_2 \approx 331.2$ g/mol

Number of moles:

$$
\text{moles of Pb(NO}_3)_2 = \frac{1.50\, \text{g}}{331.2\, \text{g/mol}} \approx 0.00453\, \text{mol}
$$

b. Calculating Moles of Sodium Sulfate

Given:
- volume of Na_2SO_4 solution = 120 mL = 0.120 L
- molarity (M) = 0.109 mol/L

Number of moles:

$$
\text{moles of Na}_2\text{SO}_4 = 0.109\, \text{mol/L} \times 0.120\, \text{L} = 0.01308\, \text{mol}
$$

c. Determining the Limiting Reactant

- The reaction requires 1:1 molar ratio of $Pb(NO_3)_2$ to Na_2SO_4.
- Available:
- $Pb(NO_3)_2$: 0.00453 mol
- Na_2SO_4: 0.01308 mol

Since 0.00453 mol of $Pb(NO_3)_2$ is present, only 0.00453 mol of Na_2SO_4 will react (assuming complete reaction), indicating $Pb(NO_3)_2$ is the limiting reagent.

d. Calculating the Expected Precipitate ($PbSO_4$)

- Moles of $PbSO_4$ formed:

$$
\text{Moles of PbSO}_4 = \text{moles of limiting reagent} = 0.00453\, \text{mol}
$$

- Mass of $PbSO_4$ precipitate:

$$
\text{Mass} = 0.00453\, \text{mol} \times 303.26\, \text{g/mol} \approx 1.37\, \text{g}
$$

Thus, approximately 1.37 grams of lead(II) sulfate will precipitate out under ideal conditions.

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4. Precipitation Conditions and Solubility Considerations

a. Ionic Product (Q) and Ksp

To determine whether $PbSO_4$ will indeed precipitate, compare the ionic product with the Ksp:

$$
Q = [\text{Pb}^{2+}] [\text{SO}_4^{2-}]
$$

- Initial concentrations (assuming complete mixing):

$$
[\text{Pb}^{2+}] = \frac{\text{moles of Pb(NO}_3)_2}{\text{total volume in liters}} = \frac{0.00453\, \text{mol}}{0.120\, \text{L}} \approx 0.03775\, \text{M}
$$

$$
[\text{SO}_4^{2-}] = \frac{\text{moles of Na}_2\text{SO}_4}{\text{total volume}} = \frac{0.01308\, \text{mol}}{0.120\, \text{L}} \approx 0.109\, \text{M}
$$

- Ionic product:

$$
Q = 0.03775 \times 0.109 \approx 0.00411
$$

Since:

$$
Q = 0.00411 \gg 1.6 \times 10^{-8}
$$

the ionic product exceeds the Ksp by a large margin, confirming that $PbSO_4$ will precipitate.

b. Precipitation Dynamics

- As $PbSO_4$ precipitates, the concentrations of Pb^{2+} and SO_4^{2-} decrease.
- The process continues until the ionic product drops to the Ksp value.
- Equilibrium is established when the ionic product equals the Ksp, and the amount of $PbSO_4$ precipitated stabilizes.

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5. Practical Implications and Applications

a. Analytical Chemistry:

- The described reaction serves as a classical gravimetric analysis method to determine lead content in a sample.
- By carefully measuring the precipitated $PbSO_4$, one can back-calculate the original amount of lead in the sample.

b. Environmental and Industrial Significance:

- Understanding precipitation reactions aids in designing processes for removing lead from wastewater.
- Lead sulfate's low solubility makes it useful in certain battery technologies and in other industrial applications.

c. Safety and Handling:

- Lead compounds are toxic; proper safety protocols must be followed during handling and disposal.
- Precipitation reactions like these are often performed in controlled laboratory environments with appropriate waste management.

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6. Additional Considerations

a. Temperature Effects:

- Solubility of $PbSO_4$ varies with temperature.
- Generally, increasing temperature slightly increases solubility, but the effect is minimal given the low Ksp.

b. Purity of Reagents:

- Impurities can affect precipitation efficiency.
- High-purity reagents are essential for precise quantitative analysis.

c. Incomplete Reactions:

- Kinetic factors or mixing inefficiencies may prevent complete precipitation.
- Stirring and adequate reaction time are critical.

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7. Summary and Conclusions

- Starting Point: 1.50 g of $Pb(NO_3)_2$ provides approximately 0.00453 mol of lead(II) nitrate.
- Reactant Quantities: The sodium sulfate solution contains about 0.01308 mol, more than enough to react with all the lead nitrate.
- Precipitated Lead Sulfate: Under ideal conditions, about 1.37 g of $PbSO_4$ will be formed, consistent with the limiting reagent calculations.
- Reaction Dynamics: The ionic product surpasses the Ksp, ensuring complete precipitation.
- Broader Context: This reaction exemplifies key principles of solubility, stoichiometry, and qualitative analysis in inorganic chemistry.

Final Thoughts

The study of such precipitation reactions not only enhances our understanding of fundamental chemical principles but also supports

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