A Solution Is Prepared By Adding 0.10 Mol Of Sodium Sulfide, Na2S , To 1.00 L Of Water. Which Statement

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Understanding the process of preparing solutions in chemistry is fundamental for students, educators, and professionals alike. When a specific amount of a solute, such as sodium sulfide (Na_2S), is added to a solvent like water, various chemical and physical phenomena occur that influence the properties of the resulting solution. This article aims to comprehensively analyze the implications of adding 0.10 mol of Na_2S to 1.00 liter of water, examining the relevant statements, chemical behavior, and solutions chemistry principles involved.

Introduction to Sodium Sulfide (Na_2S) and Its Properties

What is Sodium Sulfide?

Sodium sulfide (Na_2S) is an inorganic compound composed of sodium (Na) and sulfide (S^{2-}) ions. It appears as a yellowish solid and is commonly used in various industrial applications, including as a reducing agent, in the paper industry, and in water treatment processes.

Physical and Chemical Characteristics

- Molecular Formula: Na_2S
- Molar Mass: Approximately 78.04 g/mol
- Solubility: Highly soluble in water, forming alkaline solutions.
- Ionization in Water: Dissolves to produce sodium ions (Na^+) and sulfide ions (S^{2-}).

Preparation of the Sodium Sulfide Solution

Step-by-Step Process

1. Measuring the Solute: Accurately weigh 0.10 mol of sodium sulfide, which corresponds to approximately 7.80 grams.
2. Adding to Water: Transfer the measured Na_2S into a 1.00-liter container filled with distilled water.
3. Dissolution: Stir the mixture until Na_2S completely dissolves, resulting in a homogeneous solution.

Expected Outcome

- The solution will contain sodium ions and sulfide ions.
- The pH of the solution will be basic due to the hydrolysis of sulfide ions.

Understanding the Chemical Behavior in Solution

Ionization of Sodium Sulfide

Na_2S dissociates fully in water:
$$ \text{Na}_2\text{S} \rightarrow 2 \text{Na}^+ + \text{S}^{2-} $$

This complete dissociation classifies Na_2S as a strong electrolyte, meaning it produces a high concentration of ions in solution.

Hydrolysis of Sulfide Ions

The sulfide ion (S^{2-}) reacts with water (hydrolysis) to form hydroxide ions (OH^-) and hydrogen sulfide (H_2S):
$$ \text{S}^{2-} + \text{H}_2\text{O} \leftrightarrow \text{HS}^- + \text{OH}^- $$
$$ \text{HS}^- + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{S} + \text{OH}^- $$

This process makes the solution alkaline, with a pH typically above 7.

Analyzing the Key Statements and Questions

When preparing this solution, several statements or questions might arise regarding its properties, behavior, and implications. Here are some common statements and their analyses:

Statement 1: The Solution Is Acidic

- Analysis: Incorrect. Because sulfide ions hydrolyze to produce hydroxide ions, the solution becomes basic, not acidic.

Statement 2: The Solution Has a pH Greater Than 7

- Analysis: Correct. Due to hydrolysis, the solution is alkaline, with a pH typically around 11.

Statement 3: The Concentration of Na^+ Ions Is 0.20 M

- Analysis: Correct. Since 0.10 mol of Na_2S dissolves in 1.00 L water:
$$ \text{Na}^+ \text{ concentration} = 2 \times 0.10 \text{ mol} / 1.00 \text{ L} = 0.20 \text{ M} $$

Statement 4: The Sulfide Ions Will React with Water to Produce Hydrogen Sulfide Gas

- Analysis: Under typical conditions, the hydrolysis favors the formation of OH^-, and significant H_2S gas evolution requires acidic conditions. However, in strongly basic solutions, H_2S remains in solution as H_2S (gas) is less likely to form unless the solution is acidified.

Statement 5: The Solution Is a Strong Electrolyte

- Analysis: Correct. Na_2S fully dissociates into ions, making the solution a strong electrolyte.

Impact of Adding 0.10 Mol of Na_2S to Water

1. Changes in pH and Alkalinity

The hydrolysis of sulfide ions substantially increases the solution's pH. This alkalinity is a crucial property, especially for applications requiring basic conditions.

2. Ionic Strength and Conductivity

Adding Na_2S increases the ionic strength of water, enhancing its electrical conductivity. This is significant in electrochemistry and industrial processing.

3. Chemical Reactions and Applications

- Precipitation reactions: Na_2S can react with metal ions to form insoluble sulfides, useful in water treatment.
- pH Buffering: The solution's pH stability makes it suitable for certain chemical reactions requiring alkaline conditions.

4. Safety Considerations

Na_2S solutions are alkaline and potentially toxic. Proper handling, including gloves and eye protection, is necessary.

Practical Applications of Sodium Sulfide Solutions

Water Treatment and Pollution Control

Na_2S is used to remove heavy metals from wastewater by precipitating metal sulfides.

Industrial Synthesis

It serves as a reducing agent in chemical manufacturing.

Analytical Chemistry

Na_2S solutions are employed in titrations and other analytical procedures to detect metal ions.

Laboratory Use

Preparing Na_2S solutions allows for controlled experiments involving sulfide chemistry.

Conclusion: The Significance of the Statements and Their Implications

Understanding the behavior of sodium sulfide in aqueous solutions is critical for various scientific and industrial purposes. When 0.10 mol of Na_2S is dissolved in 1.00 liter of water, the resulting solution exhibits high alkalinity due to hydrolysis, contains specific concentrations of ions, and acts as a strong electrolyte. Recognizing whether the solution is

acidic or basic, its pH, and its reactivity helps in designing experiments, industrial processes, and safety protocols.

In summary:
- The solution is alkaline, with pH > 7.
- It contains 0.20 M Na^+ ions.
- It acts as a strong electrolyte.
- Its primary applications include water treatment, chemical synthesis, and analytical chemistry.

By understanding these principles, chemists can manipulate solution conditions to suit specific needs, ensuring safety, efficiency, and effectiveness in their applications.

Meta-description:
Learn about preparing sodium sulfide (Na_2S) solutions, their chemical behavior, pH implications, and industrial applications. Understand the key statements regarding dissolving 0.10 mol of Na_2S in water and their scientific significance.

Frequently Asked Questions

What is the significance of adding 0.10 mol of Na_2S to 1.00 L of water?

Adding 0.10 mol of Na_2S introduces sulfide ions into the solution, affecting its pH and chemical properties, and possibly leading to the formation of a basic solution.

Does dissolving Na_2S in water produce an acidic or basic solution?

Dissolving Na_2S in water typically produces a basic solution because sulfide ions (S^{2-}) react with water to produce hydroxide ions (OH^-).

What chemical reactions occur when Na_2S is added to water?

Na_2S dissociates into Na^+ and S^{2-} ions, and the sulfide ions react with water to form HS^- and OH^-, increasing the solution's basicity.

How does the amount of Na_2S added influence the pH of the solution?

Adding 0.10 mol of Na_2S increases the concentration of sulfide ions, which raises the pH, making the solution more alkaline.

What is the molarity of Na_2S in the prepared solution?

Since 0.10 mol of Na_2S is added to 1.00 L of water, the molarity of Na_2S is 0.10 M.

Would the solution containing Na_2S be considered a buffer solution?

No, a solution of Na_2S alone is not a buffer; it is a basic solution due to sulfide ions, unless additional components are present to act as buffers.

What safety precautions should be taken when preparing Na_2S solutions?

Na_2S is toxic and can release toxic hydrogen sulfide gas; therefore, it should be handled in a well-ventilated area with appropriate protective equipment such as gloves and goggles.

How does the addition of Na_2S affect the electrical conductivity of water?

Adding Na_2S increases the solution's ionic strength, thereby enhancing its electrical conductivity due to the presence of free Na^+ and S^{2-} ions.

Additional Resources

Understanding the Dissolution and Chemistry of Sodium Sulfide (Na_2S) in Water: An Analytical Perspective

The process of preparing a solution by dissolving sodium sulfide (Na_2S) in water involves a complex interplay of chemical interactions, ionization processes, and equilibrium considerations. When 0.10 mol of Na_2S is added to 1.00 liter of water, it sets the stage for various chemical phenomena that influence the solution's pH, the speciation of sulfide ions, and the potential for subsequent reactions. This article offers a comprehensive examination of this scenario, exploring the fundamental principles of solubility, acid-base chemistry, and equilibrium dynamics that underpin the behavior of sodium sulfide in aqueous media.

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1. Introduction to Sodium Sulfide and Its Relevance

1.1 Chemical Nature and Structure of Na_2S

Sodium sulfide (Na_2S) is an inorganic salt composed of two sodium ions (Na^+) and one sulfide ion (S^{2-}). It belongs to the class of alkali metal sulfides, which are typically white,

crystalline solids with high solubility in water. The sulfide ion (S^{2-}) is a strong base and a good nucleophile, readily participating in aqueous reactions that influence the solution's pH and chemical composition.

1.2 Industrial and Laboratory Significance

Na_2S has broad applications, including in the manufacturing of dyes, as a reducing agent in chemical syntheses, and in wastewater treatment. Its behavior in water is crucial for understanding its utility and potential environmental impacts, especially given its ability to generate sulfide ions that can precipitate metals or release toxic gases under certain conditions.

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2. Dissolution Process of Na_2S in Water

2.1 Dissolution Equation and Ionization

When Na_2S is introduced into water, it undergoes dissolution, breaking into its constituent ions:

$$ \text{Na}_2\text{S} (s) \rightarrow 2 \text{Na}^+ (aq) + \text{S}^{2-} (aq) $$

This process is generally considered to be complete for soluble salts like Na_2S, assuming sufficient water and no common ion effects. The ions are then free to participate in further reactions, particularly the sulfide ion.

2.2 Solubility and Dissociation Considerations

Na_2S is highly soluble in water; thus, the primary consideration becomes the behavior of the sulfide ions. The degree to which sulfide ions influence the solution depends on their subsequent reactions, especially with water, which affects pH and speciation.

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3. Aqueous Chemistry of Sulfide Ions

3.1 Basic Nature of S^{2-}

The sulfide ion (S^{2-}) is a strong base. It readily reacts with water (hydrolyzes) to produce hydroxide ions (OH^-) and hydrogen sulfide (H_2S) or bisulfide (HS^-) ions, depending on the pH. The hydrolysis can be summarized as:

$$ \text{S}^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{HS}^{-} + \text{OH}^{-} $$
$$ \text{HS}^{-} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{S} + \text{OH}^{-} $$

The extent of these reactions determines the pH of the solution and the dominant sulfide species present.

3.2 Acid-Base Equilibria of Sulfide Species

The sulfide system involves two key equilibria:

1. Dissociation of HS^-:

$$ \text{HS}^{-} \rightleftharpoons \text{H}^+ + \text{S}^{2-} \quad (K_{a2}) $$

2. Dissociation of H_2S:

$$ \text{H}_2\text{S} \rightleftharpoons \text{H}^+ + \text{HS}^{-} \quad (K_{a1}) $$

The acid dissociation constants (Ka) for these equilibria are temperature dependent but generally follow literature values:

- $K_{a1} \approx 9.1 \times 10^{-8}$
- $K_{a2} \approx 1.3 \times 10^{-13}$

These equilibria indicate that in aqueous solution, sulfide predominantly exists as HS^- and H_2S at different pH levels, with S^{2-} being predominant only at very high pH (>12).

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4. pH Considerations and Speciation of Sulfide Ions

4.1 Expected pH of the Solution

Given the hydrolysis of S^{2-}, the solution is expected to be basic. The equilibrium favors the formation of hydroxide ions, leading to a pH significantly above 7, typically in the range of 11–12.

To estimate the pH, consider the hydrolysis equilibrium of S^{2-}:

$$ \text{S}^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{HS}^{-} + \text{OH}^{-} $$

The equilibrium constant for this reaction, K_b, can be derived from K_{a2} and the

water ionization constant K_w:

$$ K_b = \frac{K_w}{K_{a2}} $$

Given $K_w = 1.0 \times 10^{-14}$ at 25°C,

$$ K_b \approx \frac{1.0 \times 10^{-14}}{1.3 \times 10^{-13}} \approx 0.077 $$

This suggests a strong base, with the hydroxide concentration and pH calculable from initial sulfide concentration.

4.2 Species Distribution at Equilibrium

Depending on the pH, sulfide exists primarily as:

- S^{2-} (dominant at pH > 12)
- HS^- (pH ~7–12)
- H_2S (pH < 7)

In our scenario, with the initial addition of 0.10 mol Na_2S to water, the solution's pH is expected to be in the high 11–12 range, favoring the presence of HS^- and some S^{2-}, with minimal H_2S due to its volatility and acid-base behavior.

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5. Implications of the Solution's Composition

5.1 Basicity and Potential for Gas Evolution

The basic nature of the solution means that it can readily participate in further reactions, such as:

- Release of hydrogen sulfide (H_2S) gas if the pH drops or if acids are introduced.
- Precipitation of metal sulfides if metal ions are present, which is relevant in environmental contexts and industrial processes.

5.2 Environmental and Safety Considerations

Sulfide ions are toxic and can release H_2S, a hazardous gas with a characteristic rotten egg smell. The high pH and presence of sulfide demand careful handling and appropriate safety measures.

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6. Quantitative Analysis of the Solution

6.1 Calculating Hydroxide Concentration

Assuming complete dissociation and hydrolysis, the hydroxide concentration (OH^-) can be estimated:

$$ [\text{OH}^-] \approx \sqrt{\frac{K_b \times C_{S^{2-}}}{1 + \frac{K_b}{K_{a2}}}} $$

Given the initial sulfide concentration:

$$ C_{S^{2-}} = 0.10\, \text{mol} $$

and considering the strong basic nature, the pOH can be approximated as:

$$ \text{pOH} \approx -\log [\text{OH}^-] $$

which leads to:

$$ \text{pH} = 14 - \text{pOH} $$

Estimations suggest pH values around 11–12, confirming the basicity.

6.2 Final Species Distribution

Using the pH, the dominant sulfide species can be predicted:

- At pH > 12: Mainly S^{2-}
- At pH 9–12: HS^- and some S^{2-}
- At pH < 7: H_2S dominates

In our case, the solution would primarily contain HS^- and S^{2-}, with negligible H_2S due to its volatility and the high pH environment.

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7. Summary and Conclusions

The addition of 0.10 mol of sodium sulfide to 1.00 liter of water results in a highly basic solution, owing to the hydrolysis and ionization of sulfide ions. The predominant species in the solution are hydroxide ions, HS^-, and S^{2-}, with the p

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