### \*\*Lesson 4: Hydrates: Their Formulas and Reactions\*\*

### # \*\*Unit 3: Chemical Reactions and Stoichiometry\*\*

**Chapter 10: Stoichiometry**

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### \*\*1. Big Idea:\*\*

Hydrates are compounds that include water molecules as part of their structure, and understanding their composition helps in predicting chemical reaction outcomes.

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### \*\*2. Essential Questions:\*\*

- **How do hydrates form, and how can we determine their composition?**

**Answer:** Hydrates form when ionic compounds trap water molecules within their crystal lattice during crystallization. Their composition can be determined through chemical formulas, which express the ratio of water molecules to the compound, and by experimentally calculating the percent by mass of water.

- **How do hydrates affect chemical reactions in which they are involved?**

**Answer:** Hydrates release their water of crystallization when heated or chemically altered. This water can contribute to the reaction as a reactant or product, so it must be considered in stoichiometric calculations.

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### \*\*3. Phenomenon-Based Learning:\*\*

**Unit Phenomenon:**

**Question:** How can chemical reactions help improve safety features?

**Background:** In car airbags, chemical reactions rapidly produce harmless gases to inflate the bag during an accident. The gas must be safe and predictable, which depends on precise chemical formulas and reaction ratios. For instance, sodium metal, if uncontrolled, can react with moisture in air to create hazardous conditions.

**Chapter Phenomenon:**

Now you have several ways to measure matter—by quantity of particles, mass, or volume. But how do those quantities relate to each other in a chemical equation? What is the ratio in which they react?

**Lesson Phenomenon:**

Water plays an essential role in many chemical compounds, not just as a separate reactant or product. In hydrates, water molecules are built into the compound's formula. Understanding hydrates ensures accurate stoichiometric calculations.

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### \*\*4. Vocabulary:\*\*

- **Anhydrous formula:** The chemical formula of a substance after all water has been removed.

- **Greek prefix:** Prefixes (like mono-, di-, tri-) that indicate the number of water molecules in a hydrate formula.

- **Hydrates:** Compounds that include water molecules as part of their structure.

- **Hydrate formula:** The chemical formula of a hydrate, including the ratio of water to the compound (e.g., CuSO₄·5H₂O).

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### \*\*5. SMART Objectives:\*\*

- Calculate the percent by mass of water in a hydrate.

- Predict the products of reactions involving hydrates.

- Analyze the factors that affect the percent yield of a reaction.

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### \*\*6. Engage (Ignite):\*\*

**Phenomenon-Based Task:**

Observe how water affects chemical compounds by investigating a simple household hydrate: baking soda (sodium bicarbonate, NaHCO₃).

**Instructions:**

1. Gather materials: baking soda, heat-resistant dish, small-scale kitchen torch or Bunsen burner, and a digital kitchen scale.

2. Weigh a small amount of baking soda (about 5 grams) in a dish. Record this value.

3. Heat the baking soda gently in the dish until it appears dry and crumbly. Allow it to cool.

4. Reweigh the baking soda once cooled.

**Questions:**

1. **What caused the change in mass after heating?**

**Answer:** The heating process likely drove out any water molecules or gases associated with the compound.

2. **Could this change affect how much product forms in a reaction? Why?**

**Answer:** Yes, because the water that escaped was part of the compound's original mass. This must be accounted for in stoichiometric calculations.

3. **How does this relate to hydrates?**

**Answer:** Hydrates release water when heated, similar to how the water content in baking soda may have been removed. This affects the accuracy of measurements in reactions involving hydrates.

**AI Tool Integration:**

Use AI chemistry tools (e.g., PhET Interactive Simulations) to visualize the structure of hydrates and their water molecules. Encourage exploration by posing questions like:

- "What happens to the molecular structure when water is removed from a hydrate?"

- "How does the number of water molecules affect the overall formula?"

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### \*\*7. Pre-Explore (Direct Instruction):\*\*

**Prior Knowledge:**

Students may already be familiar with simple chemical formulas (e.g., H₂O, NaCl) and the role of water in physical states (e.g., evaporation, freezing). They may also recall basic calculations involving mass and volume from earlier grades.

**Real-World Connection:**

Hydrates are found in everyday substances like epsom salts (MgSO₄·7H₂O), plaster of Paris, and even concrete. When you heat epsom salts during use, the water leaves its structure, making the compound anhydrous. This process is crucial in construction and medicine.

**Background Information:**

- **How Hydrates Form:** Hydrates form when ionic compounds crystallize from water solutions. Water molecules get trapped in a repeating pattern within the compound's structure.

- **How to Express Hydrates:** The formula indicates the main compound and the number of water molecules with a dot, like CuSO₄·5H₂O. Here, 5 water molecules are associated with each unit of CuSO₄.

- **Heating Hydrates:** Heating removes water and leaves the anhydrous form of the compound. For example, heating CuSO₄·5H₂O results in CuSO₄ and water vapor.

**Interactive Elements:**

- Scaffolded Note-Taking: Provide a guided note sheet that includes partially completed hydrate formulas (e.g., CaCl₂·\_?\_H₂O) for learners to fill in.

- Discussion Prompt: "Why might removing water from a hydrate be important during a chemical reaction? Can you think of a situation where adding water back to a compound is helpful?"

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# Lesson 4: Hydrates, Their Formulas, and Reactions

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**Unit Phenomenon Reminder: How Can Chemical Reactions Help Improve Safety Features?**

Car accidents are a serious issue, and chemical reactions play a big role in making cars safer. For instance, airbags inflate using gases formed from chemical reactions, and it’s important that these reactions produce safe products. But what about water? Did you know that water can also be a part of some chemical substances and affect how they behave in a reaction? Let’s dive into how water interacts with compounds called **hydrates** and how understanding hydrates is key to predicting and measuring chemical reactions.

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## \*\*What Are Hydrates?\*\*

We know water as a tricky molecule—it can exist as a liquid, solid (ice), and gas (steam). But water is even trickier because sometimes it doesn’t stand alone. In some chemical compounds, water molecules are **trapped** and become part of their structure. These special compounds are called **hydrates**.

A **hydrate** is a compound that contains water molecules within its crystal structure. The water is not loosely attached to the surface; it’s actually part of the compound. To write the formula of a hydrate, we add water using a special notation. For example, the hydrate named **copper(II) sulfate pentahydrate** includes five water molecules for each unit of copper sulfate. Its formula looks like this:

**CuSO₄ · 5H₂O**

The **· 5H₂O** part tells us there are five water molecules in the structure. These water molecules are called **water of hydration**.

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### \*\*How Are Hydrates Different from Anhydrous Compounds?\*\*

When you **remove** the water from a hydrate, it becomes an **anhydrous compound**. The prefix “an-” means “without,” so an anhydrous compound is just the part of the hydrate that’s left after the water is gone.

For example:

- Hydrate: **CuSO₄ · 5H₂O** (blue crystals)

- Anhydrous Compound: **CuSO₄** (white powder)

When hydrates lose their water, they can change:

- **Color**: Hydrated copper(II) sulfate is blue, but its anhydrous form is white.

- **Mass**: Removing water reduces the mass of the compound.

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### \*\*Why Do We Care About Hydrates?\*\*

Hydrates are important in real-world scenarios, from food preservation to construction and even medicine. For example:

- **Medicine**: Hydrate compounds in drugs help control how quickly medicines dissolve in the body.

- **Construction**: Gypsum (CaSO₄ · 2H₂O) is a hydrate used to make drywall. Its ability to lose and gain water makes it useful for construction.

Hydrates also affect chemical reactions. If you use a hydrate in a reaction, you need to account for its water. That means you have to measure it and include it in your calculations.

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### \*\*Formula of a Hydrate\*\*

To describe a hydrate properly, we use its **hydrate formula**, which tells us:

1. The chemical formula of the compound (e.g., CuSO₄)

2. The number of water molecules (e.g., 5H₂O)

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### \*\*Greek Prefixes for Counting Water Molecules\*\*

To name hydrates, we use Greek prefixes to show the number of water molecules. Here’s a handy table of prefixes you’ll need to know:

| **Number** | **Prefix** |

|------------|------------|

| 1 | Mono- |

| 2 | Di- |

| 3 | Tri- |

| 4 | Tetra- |

| 5 | Penta- |

| 6 | Hexa- |

| 7 | Hepta- |

| 8 | Octa- |

| 9 | Nona- |

| 10 | Deca- |

For example:

- **MgSO₄ · 7H₂O** = magnesium sulfate heptahydrate

- **Na₂CO₃ · 10H₂O** = sodium carbonate decahydrate

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## \*\*Calculating the Percent by Mass of Water in a Hydrate\*\*

The **percent by mass of water** tells us how much of the hydrate’s mass comes from water. To calculate it, we follow these steps:

1. **Find the molar mass of the hydrate** (including the water molecules).

2. **Find the total mass of the water molecules** in the hydrate.

3. Use the formula:

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\text{Percent by Mass of Water} = \left( \frac{\text{Mass of Water}}{\text{Mass of Hydrate}} \right) \times 100

\]

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### \*\*Sample Problem 1: Calculating Percent by Mass of Water\*\*

**Problem**: What is the percent by mass of water in CuSO₄ · 5H₂O?

**Step 1**: Find the molar mass of the hydrate.

- Molar mass of CuSO₄ = 63.55 (Cu) + 32.07 (S) + 16.00 × 4 (O) = 159.62 g/mol

- Molar mass of 5H₂O = 5 × (2 × 1.01 + 16.00) = 90.10 g/mol

- Total molar mass = 159.62 + 90.10 = 249.72 g/mol

**Step 2**: Find the total mass of water.

- Mass of 5H₂O = 90.10 g/mol

**Step 3**: Calculate the percent by mass of water.

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\text{Percent by Mass of Water} = \left( \frac{90.10}{249.72} \right) \times 100 \approx 36.08\%

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**Answer**: The percent by mass of water in CuSO₄ · 5H₂O is **36.08%**.

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**Practice Problem 1**: What is the percent by mass of water in BaCl₂ · 2H₂O?

(**Hint: Use Ba = 137.33, Cl = 35.45, H = 1.01, O = 16.00**)

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## \*\*Predicting Products of Reactions Involving Hydrates\*\*

Sometimes hydrates are heated, causing them to lose water and form anhydrous compounds. This process is called **dehydration**. The products often include the anhydrous compound and water vapor.

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### \*\*Sample Problem 2: Predicting Products\*\*

**Problem**: What happens when MgSO₄ · 7H₂O is heated?

**Answer**: The hydrate loses water, so the products are:

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\text{MgSO₄ · 7H₂O} \xrightarrow{\text{heat}} \text{MgSO₄} + 7\text{H₂O}

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**Practice Problem 2**: Write the reaction for heating Na₂CO₃ · 10H₂O.

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## \*\*Factors Affecting Percent Yield in Reactions with Hydrates\*\*

When working with hydrates in a reaction, the **percent yield** can vary depending on factors like:

- **Incomplete reactions**: If not all the hydrate reacts, the yield will be lower.

- **Loss of water**: Losing water accidentally can affect calculations.

- **Impurities**: Extra substances can throw off measurements.

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### \*\*Sample Problem 3: Percent Yield\*\*

**Problem**: If 25.0 g of CuSO₄ · 5H₂O is heated and produces 15.0 g of CuSO₄, what is the percent yield?

**Step 1**: Calculate the theoretical yield.

- Molar mass of CuSO₄ · 5H₂O = 249.72 g/mol

- Molar mass of CuSO₄ = 159.62 g/mol

- Mass ratio: 159.62 / 249.72 = 0.6394

- Theoretical yield = 25.0 g × 0.6394 ≈ 15.99 g

**Step 2**: Calculate the percent yield.

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\text{Percent Yield} = \left( \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \right) \times 100

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\text{Percent Yield} = \left( \frac{15.0}{15.99} \right) \times 100 \approx 93.81\%

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**Answer**: The percent yield is **93.81%**.

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**Practice Problem 3**: A reaction starts with 50.0 g of BaCl₂ · 2H₂O and produces 35.0 g of BaCl₂. What is the percent yield?

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## \*\*Evaluate (Progress Check)\*\*

1. **What is a hydrate? How is it different from an anhydrous compound?**

- **(Answer: A hydrate is a compound that includes water molecules in its structure. An anhydrous compound has no water.)**

2. **What is the percent by mass of water in Na₂CO₃ · 10H₂O?**

- **(Answer: Use the molar masses to calculate: ~62.93% water.)**

3. **What are the products of heating CaSO₄ · 2H₂O?**

- **(Answer: The products are CaSO₄ and 2H₂O.)**

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By understanding hydrates and their role in chemical reactions, you’re building a foundation for solving real-world problems, like designing safe airbags or accurate measurements in chemistry labs. Keep practicing to master these concepts!

### Chemistry Lesson: Understanding the Basics of Acids, Bases, and pH

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### 9. \*\*Elaborate (Power Up)\*\*

**Open-Ended Questions or Mini-Tasks**:

1. Why do acids and bases react with each other to form water and a salt? Can you think of examples of these reactions in daily life?

- **Answer**: Acids and bases neutralize each other because their ions (H⁺ from the acid and OH⁻ from the base) combine to form water (H₂O). For example, if you spill vinegar (acid) on your hands, washing with soapy water (base) neutralizes the acid.

2. Imagine you're testing the water in a local river. The pH is 5.6. What might this tell you about the river's health or pollution levels?

- **Answer**: A pH of 5.6 indicates the water is slightly acidic. This could suggest acid rain or industrial pollution. Healthy river water typically has a neutral pH (around 7).

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### 10. \*\*Progress Check (Final Evaluation)\*\*

**Debate Question**:

- "Should we use chemical treatments to neutralize acid rain effects, or focus on reducing pollution at its source?"

- **Discussion Points**:

- Pros of chemical treatments: Immediate benefits for plant and animal life.

- Cons: Temporary solution, can be costly and involve risks.

- Pros of reducing pollution: Long-term solution, prevents future damage.

- Cons: Takes time and requires global cooperation.

**Paragraph (Debate Context)**:

Acid rain can damage forests, lakes, and buildings. Some people argue for spraying lime (a base) to neutralize acidic soils and waters. Others say we should focus on reducing pollution from cars and factories that release acidic gases like sulfur dioxide and nitrogen oxide. Both approaches have advantages and challenges, and finding a balance is key to protecting the environment.

**MCQ**:

What is the best reason for focusing on reducing pollution as a solution to acid rain?

a) It is faster and cheaper than using chemical treatments.

b) It provides a long-term solution to prevent the root cause of acid rain.

c) It helps clean up only the areas most affected by acid rain.

d) It requires no cooperation between people or governments.

- **Answer**: b) It provides a long-term solution to prevent the root cause of acid rain.

**Assessment Questions**

**ACT-Style Multiple-Choice Questions**:

1. Which of the following is true of acids?

a) They have a slippery texture.

b) They turn red litmus paper blue.

c) They release H⁺ ions in water.

d) They neutralize salts to form bases.

- **Answer**: c) They release H⁺ ions in water.

- **Explanation**: Acids release hydrogen ions (H⁺) in water, which is a key property of acids — unlike bases, which release OH⁻ ions.

2. A substance has a pH of 11. Which of the following statements is correct?

a) It is an acid.

b) It is a base with low alkalinity.

c) It is a strong base.

d) It is neutral.

- **Answer**: c) It is a strong base.

- **Explanation**: Substances with high pH values (above 10) are strong bases.

3. What is the main product when an acid reacts with a base?

a) A gas

b) A metal

c) Salt and water

d) Sugar

- **Answer**: c) Salt and water

- **Explanation**: The reaction of an acid and base is called neutralization. It always produces salt and water.

4. If lemon juice (pH 2) is added to baking soda solution (pH 9), what is the likely outcome?

a) The solution stays acidic.

b) The solution becomes neutral or slightly basic.

c) The solution becomes strongly basic.

d) The pH drops below 2.

- **Answer**: b) The solution becomes neutral or slightly basic.

- **Explanation**: Lemon juice is acidic, while baking soda is basic. Adding them together neutralizes their effects, moving the pH closer to 7.

**Long-Answer Questions**:

1. Explain why soap feels slippery and relates this to the concept of bases.

- **Answer**: Soap is slippery because it is a base. Bases react with oils on your skin to form soap-scum, reducing friction and creating the slippery feeling.

2. Why is it important for the pH of drinking water to be close to 7?

- **Answer**: Drinking water with a pH too high or low can harm the body. Acidic water may dissolve harmful metals like lead, while basic water can taste unpleasant and irritate the digestive system.

3. Describe a real-life scenario where neutralization reactions are applied, and explain the science behind it.

- **Answer**: One real-life example is farmers adding lime to soil to reduce acidity. Lime contains calcium carbonate, a base that reacts with acids in the soil, forming water and neutral salts. This balances the soil’s pH and improves crop growth.

4. How would you explain the concept of pH to someone who has never heard of it before?

- **Answer**: pH measures how acidic or basic a substance is on a scale from 0 to 14. Acids have low pH (0-6), such as lemon juice, while bases have high pH (8-14), like baking soda. A pH of 7 is neutral, like pure water.

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### 11. \*\*Extend (Beyond the Lesson)\*\*

**Real-World Challenges**:

1. Test the pH of various household items (e.g., vinegar, soap, soda) using pH strips. Record the results and identify whether each substance is acidic, basic, or neutral.

2. Research and present a short report on a local environmental issue related to pH, such as acid rain, soil acidification, or water quality.

**Long-Term Reinforcement Tasks**:

- Monitor pH changes in a glass of water left uncovered for a week. Discuss how CO₂ in the air might affect it.

- Write a journal entry from the perspective of a molecule in a neutralization reaction, describing what happens during the process.

**Hints for Upcoming Topics**:

- "Next, we'll explore how chemical reactions produce energy—such as the heat you feel during certain reactions. Did you know neutralization reactions can give off energy too?"