# Unit: Unit 3: Chemical Reactions and Stoichiometry

## Chapter: Chapter 10: Stoichiometry

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

### Lesson Plan: 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 contain water molecules as part of their structure, and understanding their formulas and reactions helps in predicting chemical behavior and calculating stoichiometric relationships.

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### 2. Phenomenon-Based Learning:

**Unit Phenomenon:**

How can chemical reactions help improve safety features?

**Chapter Phenomenon:**

How do measurable quantities of matter relate to each other in a chemical equation, and what ratios do they react in?

**Lesson Phenomenon:**

Water often plays a surprising role in chemical reactions. In hydrates, water is not just present—it’s part of the compound’s formula. These water molecules can change how a compound reacts and how much product is formed. For example, what happens when a hydrate is heated? Does it lose water, and if so, how does that affect the reaction?

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### 3. Vocabulary:

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

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

- **Hydrate formula:** The chemical formula of a hydrate, showing the ratio of water molecules to the compound.

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

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### 4. 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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### 5. Engage (Ignite):

**Hands-On Task:**

**"What Happens When Hydrates Lose Water?"**

**Materials Needed:**

- Epsom salt (magnesium sulfate heptahydrate, MgSO₄·7H₂O)

- Heat source (e.g., a Bunsen burner or candle)

- Aluminum foil or a small dish

- Kitchen scale (optional)

**Procedure:**

1. Weigh a small amount of Epsom salt and record its mass (optional).

2. Place the salt on a piece of aluminum foil or in a dish.

3. Gently heat the salt for a few minutes and observe what happens.

4. Let the salt cool and reweigh it (if a scale is available).

**Follow-Up Questions:**

1. What did you observe when the Epsom salt was heated?

- **Answer:** The salt lost water and turned from a crystalline solid to a powdery, anhydrous form.

2. How would you describe the role of water in the original compound?

- **Answer:** The water was part of the hydrate’s structure and was released when heated.

3. How could this experiment relate to airbags in cars?

- **Answer:** Just like hydrates release water when heated, other compounds release gases during chemical reactions, which can inflate airbags.

**AI Tool Integration:**

Use an AI-based chemistry simulation tool (like ChemCollective or PhET Interactive Simulations) to model what happens at the molecular level when a hydrate is heated. Ask the tool:

- "What does the structure of MgSO₄·7H₂O look like before and after heating?"

- "How does the mass of the compound change when water is removed?"

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### 6. Pre-Explore (Direct Instruction):

**Building on Prior Knowledge:**

- Recall from earlier grades how water can exist in different states (solid, liquid, gas) and how it can participate in physical and chemical changes.

- In Grade 7, dissolving salt in water was an example of a physical change. In this lesson, water is chemically bound to a compound, forming a hydrate.

**Real-World Connection:**

- Epsom salt (a common hydrate) is used in baths for muscle relaxation. When heated, it loses water and becomes anhydrous.

- In car airbags, chemical reactions release gases that inflate the bag. Similarly, hydrates release water when heated, which can drive certain reactions.

**Background Information:**

Hydrates are compounds that include water molecules in their structure. For example, copper(II) sulfate pentahydrate (CuSO₄·5H₂O) contains five water molecules for every copper sulfate unit. When heated, hydrates lose their water and become anhydrous. This change can be represented by a chemical equation:

\[ CuSO₄·5H₂O \xrightarrow{\text{heat}} CuSO₄ + 5H₂O \]

The water in hydrates is not "free" water like in a glass—it’s part of the compound’s crystalline structure. This is why hydrates have distinct properties, like a specific color or texture, that change when they lose water.

**Interactive Notes:**

- Write the formula for copper(II) sulfate pentahydrate on the board: CuSO₄·5H₂O.

- Discuss the Greek prefix "penta-" (meaning five) and how it tells us the number of water molecules.

- Ask: "What would the formula be for a hydrate with three water molecules?"

- **Answer:** The formula would include the prefix "tri-," so an example could be CaCl₂·3H₂O.

**Scaffolded Questions:**

1. What is the difference between a hydrate and an anhydrous compound?

- **Answer:** A hydrate contains water molecules in its structure, while an anhydrous compound does not.

2. Why do hydrates lose water when heated?

- **Answer:** Heat provides energy to break the bonds between the water molecules and the rest of the compound.

This foundational knowledge sets the stage for exploring hydrate formulas, percent composition, and their role in chemical reactions.

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**Next Steps:**

The "Explore" phase will involve calculating the percent by mass of water in a hydrate and predicting the products of reactions involving hydrates.

# Lesson 4: Hydrates – Their Formulas and Reactions

## Introduction: Water’s Role in Chemistry

Water is a fascinating substance. You probably know it as H₂O, the liquid we drink and use every day. But did you know water can also "team up" with other substances to form something called a \*hydrate\*? Hydrates are special compounds that include water molecules as part of their structure. These water molecules are not just hanging around—they are actually part of the compound's formula!

Hydrates are everywhere in the world around us. For example, the plaster used to make casts for broken bones contains a hydrate called calcium sulfate dihydrate. When heated, the water in the hydrate is released, and the plaster hardens. In this lesson, we’ll explore what hydrates are, how they work in chemical reactions, and how to calculate the amount of water they contain.

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## What Are Hydrates?

### Definition of Hydrates

A \*hydrate\* is a compound that contains water molecules as part of its crystal structure. These water molecules are not chemically bonded in the same way as the atoms in the rest of the compound, but they are still an important part of the substance.

For example, copper(II) sulfate pentahydrate has the formula **CuSO₄·5H₂O**. This means that for every one unit of copper(II) sulfate (CuSO₄), there are five water molecules (H₂O) attached to it.

### Vocabulary to Know:

- **Hydrate**: A compound that contains water molecules within its structure.

- **Anhydrous**: A substance that does not contain water.

- **Greek Prefixes**: Used to indicate the number of water molecules in a hydrate. For example:

- Mono = 1

- Di = 2

- Tri = 3

- Tetra = 4

- Penta = 5

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## Real-World Example: Hydrates in Everyday Life

Have you ever opened a package of silica gel beads? These are often found in new shoes, bags, or electronics to keep moisture away. Silica gel is an example of an anhydrous substance—it absorbs water from the air and becomes a hydrate. This helps prevent damage to the items by keeping them dry.

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## How Do Hydrates Affect Chemical Reactions?

Hydrates can play a big role in chemical reactions. When a hydrate is heated, the water molecules are released, leaving behind an \*anhydrous\* compound. This process is called **dehydration**.

For example:

**CuSO₄·5H₂O (s) → CuSO₄ (s) + 5H₂O (g)**

In this reaction, copper(II) sulfate pentahydrate is heated, and the water molecules are released as water vapor, leaving behind anhydrous copper(II) sulfate.

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

One of the most important things we can do with hydrates is calculate how much of their mass comes from water. This is called the **percent by mass of water**.

### Formula:

\[

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

\]

### Example Problem:

A sample of magnesium sulfate heptahydrate (MgSO₄·7H₂O) has a total mass of 246 g. How much of this mass comes from water?

1. **Step 1: Find the molar masses of each part of the hydrate.**

- MgSO₄ = 24.3 (Mg) + 32.1 (S) + 64.0 (O₄) = **120.4 g/mol**

- 7H₂O = 7 × (2.0 (H) + 16.0 (O)) = **126.0 g/mol**

2. **Step 2: Add the masses together to find the total molar mass.**

- Total molar mass = 120.4 + 126.0 = **246.4 g/mol**

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

- Percent by mass of water = \(\frac{126.0}{246.4} \times 100 = 51.1\%\)

**Answer:** The percent by mass of water in magnesium sulfate heptahydrate is **51.1%**.

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### Practice Problem:

A sample of barium chloride dihydrate (BaCl₂·2H₂O) has a total mass of 244 g. What percent of its mass comes from water?

**Answer:**

1. Molar mass of BaCl₂ = 137.3 (Ba) + 2 × 35.5 (Cl) = **208.3 g/mol**

2. Molar mass of 2H₂O = 2 × (2.0 (H) + 16.0 (O)) = **36.0 g/mol**

3. Total molar mass = 208.3 + 36.0 = **244.3 g/mol**

4. Percent by mass of water = \(\frac{36.0}{244.3} \times 100 = 14.7\%\)

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## Predicting the Products of Reactions Involving Hydrates

When hydrates are heated, they lose water and become anhydrous compounds. This is an example of a **decomposition reaction**.

### Example Reaction:

**CaSO₄·2H₂O (s) → CaSO₄ (s) + 2H₂O (g)**

In this reaction, calcium sulfate dihydrate is heated, releasing two water molecules as vapor and leaving behind anhydrous calcium sulfate.

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### Practice Problem:

Write the products of heating sodium carbonate decahydrate (Na₂CO₃·10H₂O).

**Answer:**

**Na₂CO₃·10H₂O (s) → Na₂CO₃ (s) + 10H₂O (g)**

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## Factors That Affect the Percent Yield of a Reaction

In real-world experiments, we rarely get 100% of the products we expect. The **percent yield** tells us how much of the expected product we actually obtained.

### Formula:

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

\]

### Factors That Affect Percent Yield:

1. **Incomplete Reactions:** Not all reactants may fully react.

2. **Loss of Product:** Some product may be lost during transfer or measurement.

3. **Side Reactions:** Other reactions may occur, using up some of the reactants.

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### Example Problem:

In a lab, you heat 10.0 g of CuSO₄·5H₂O and expect to produce 6.4 g of anhydrous CuSO₄. However, you only collect 5.8 g. What is the percent yield?

1. **Step 1: Use the formula for percent yield.**

- Percent yield = \(\frac{5.8}{6.4} \times 100 = 90.6\%\)

**Answer:** The percent yield is **90.6%**.

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### Practice Problem:

You heat 15.0 g of MgSO₄·7H₂O and expect to produce 7.3 g of anhydrous MgSO₄. If you collect 6.5 g, what is the percent yield?

**Answer:**

Percent yield = \(\frac{6.5}{7.3} \times 100 = 89.0\%\)

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## Progress Check

### Question 1:

What is a hydrate?

**Answer:** A hydrate is a compound that contains water molecules within its structure.

### Question 2:

What happens to a hydrate when it is heated?

**Answer:** When a hydrate is heated, it loses its water molecules and becomes an anhydrous compound.

### Question 3:

Calculate the percent by mass of water in Na₂CO₃·10H₂O.

**Answer:**

1. Molar mass of Na₂CO₃ = 23.0 × 2 (Na) + 12.0 (C) + 16.0 × 3 (O) = **106.0 g/mol**

2. Molar mass of 10H₂O = 10 × (2.0 (H) + 16.0 (O)) = **180.0 g/mol**

3. Total molar mass = 106.0 + 180.0 = **286.0 g/mol**

4. Percent by mass of water = \(\frac{180.0}{286.0} \times 100 = 62.9\%\)

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By understanding hydrates, their formulas, and how they react, you’ve taken another step in connecting chemistry to the real world. Keep exploring!

### 9. Elaborate (Power Up)

Let’s dive deeper into the topic of chemical reactions. Here are some open-ended questions and mini-tasks to challenge your understanding:

**1. Open-Ended Question:**

Why do you think temperature affects the rate of a chemical reaction? Can you think of a real-life example where this is important?

**Answer:**

Temperature affects the speed of particles. Higher temperatures make particles move faster, increasing the chances of collisions and reactions. A real-life example is cooking—higher heat speeds up the cooking process by increasing the reaction rate between food molecules.

**2. Mini-Task:**

Design a simple experiment to test how surface area affects the rate of a reaction. For example, how does crushing a tablet versus leaving it whole change how quickly it dissolves in water?

**Answer:**

Crushing the tablet increases its surface area, allowing more particles to interact with the water at once. This speeds up the reaction. You could test this by timing how long it takes for the tablet to dissolve in each form.

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### 10. Final Evaluation

**Debate Question:**

"Should we prioritize renewable energy sources over fossil fuels, considering the chemical reactions involved in energy production?"

**Discussion Points:**

- Fossil fuels release energy through combustion, but they also produce carbon dioxide, contributing to climate change.

- Renewable energy sources like solar and wind don’t rely on combustion, but they may require chemical storage systems like batteries.

- Which is more sustainable in the long term?

**Paragraph:**

Fossil fuels and renewable energy sources both have pros and cons when it comes to energy production. Fossil fuels are reliable and energy-dense but contribute to pollution and global warming. Renewable sources are cleaner but depend on weather and often need advanced storage systems. Understanding the chemistry behind energy production can help us make informed decisions about our future.

**MCQ:**

Which of the following is a key chemical reaction in fossil fuel energy production?

A. Photosynthesis

B. Combustion

C. Electrolysis

D. Neutralization

**Answer:**

**B. Combustion**

Explanation: Combustion is the reaction of a fuel with oxygen to release energy, usually in the form of heat and light. This is the primary reaction in fossil fuel energy production.

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**Assessment Questions**

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

1. Which factor does NOT affect the rate of a chemical reaction?

A. Temperature

B. Surface area

C. Color of the reactants

D. Concentration

**Answer:** C. Color of the reactants

**Explanation:** Reaction rates depend on factors like temperature, surface area, and concentration, but the color of reactants has no impact on the reaction speed.

2. What happens to the particles in a reaction when the temperature is increased?

A. They slow down.

B. They move faster and collide more often.

C. They stop moving.

D. They change into new particles.

**Answer:** B. They move faster and collide more often.

**Explanation:** Higher temperatures give particles more energy, increasing their speed and the frequency of collisions.

3. Which of the following is an example of an exothermic reaction?

A. Melting ice

B. Boiling water

C. Burning wood

D. Dissolving sugar

**Answer:** C. Burning wood

**Explanation:** Burning wood releases heat and light, making it an exothermic reaction.

4. A catalyst is added to a reaction. What will happen?

A. The reaction will stop.

B. The reaction will slow down.

C. The reaction will speed up without being used up.

D. The reaction will produce more products.

**Answer:** C. The reaction will speed up without being used up.

**Explanation:** Catalysts lower the activation energy needed for a reaction, speeding it up without being consumed.

**Long-Answer Questions:**

1. Explain how increasing the concentration of reactants affects the rate of a chemical reaction.

**Answer:** Increasing the concentration of reactants means there are more particles in the same space. This increases the likelihood of collisions between particles, speeding up the reaction.

2. Describe an experiment you could perform to test how temperature affects the rate of a reaction.

**Answer:** You could dissolve sugar in water at different temperatures (e.g., cold, room temperature, and hot water) and time how long it takes to dissolve completely. The hotter water should dissolve the sugar faster because the particles are moving more quickly.

3. Why are catalysts important in industrial chemical reactions?

**Answer:** Catalysts are important because they speed up reactions without being consumed, making processes more efficient and cost-effective. For example, in the production of ammonia, a catalyst helps the reaction occur at a lower temperature and pressure.

4. Compare and contrast exothermic and endothermic reactions with examples.

**Answer:** Exothermic reactions release energy, usually as heat or light (e.g., combustion of wood). Endothermic reactions absorb energy from their surroundings (e.g., melting ice). Both involve energy changes but in opposite directions.

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### 11. Extend (Beyond the Lesson)

**Tasks and Challenges:**

1. **Real-World Application:** Research how chemical reactions are used in everyday life, such as in cooking, cleaning, or energy production. Write a short report on one example.

2. **Experiment at Home:** Try dissolving sugar or salt in water at different temperatures and observe how temperature affects the rate of dissolution.

**Reinforcement Questions:**

- Why do we store some foods in the freezer? How does temperature affect the chemical reactions that cause food to spoil?

- How might the principles of reaction rates apply to designing faster-acting medicines?

**Hints for Upcoming Topics:**

In the next lesson, we’ll explore chemical equilibrium. Did you know that some reactions can go forward and backward? Stay tuned to learn how chemists control these reactions to make useful products!