# Unit 3: Chemical Reactions and Stoichiometry

## Chapter 10: Stoichiometry

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

### 1. Big Idea:

Hydrates are compounds that include water molecules as part of their structure, and understanding their formulas helps us predict their behavior in chemical reactions.

---

### 2. Phenomenon-Based Learning:

### # Unit Phenomenon:

How can chemical reactions help improve safety features?

- Example: The rapid inflation of airbags in cars relies on chemical reactions that produce gas.

### # Chapter Phenomenon:

How do the quantities of matter relate to each other in a chemical equation?

- Example: The ratio of reactants and products in a reaction determines how much gas is produced in an airbag.

### # Lesson Phenomenon:

Water often plays a surprising role in chemical reactions. Sometimes it stands alone, but other times, it is part of a compound's formula. These compounds, called hydrates, can affect the outcome of reactions.

- Example: Copper(II) sulfate pentahydrate (CuSO₄·5H₂O) changes color when heated because the water is removed.

**Task:**

- Investigate what happens when a hydrate is heated.

- Heat a small amount of copper(II) sulfate pentahydrate (CuSO₄·5H₂O) in a test tube and observe the color change.

- Discuss why the color changes and how this relates to the water in the hydrate.

---

### 3. Vocabulary:

- **Hydrates**: Compounds that have water molecules chemically bonded to them.

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

- **Greek Prefix**: A prefix used to indicate the number of water molecules in a hydrate (e.g., mono-, di-, tri-).

- **Hydrate Formula**: The chemical formula that shows the number of water molecules associated with a compound (e.g., CuSO₄·5H₂O).

---

### 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.

---

### 5. Engage (Ignite):

### # Hands-On Task:

**Objective:** Explore how hydrates lose water when heated.

**Materials Needed:**

- Small sample of copper(II) sulfate pentahydrate (CuSO₄·5H₂O)

- Test tube

- Bunsen burner or alcohol lamp

- Tongs

- Safety goggles

**Procedure:**

1. Place a small amount of copper(II) sulfate pentahydrate in a test tube.

2. Heat the test tube gently over a flame while observing any changes.

3. Record what happens to the color of the compound.

**Follow-Up Questions:**

1. What happened to the color of the copper(II) sulfate after heating?

- **Answer:** It changed from blue to white.

2. Why do you think the color changed?

- **Answer:** The water molecules in the hydrate were removed, leaving the anhydrous form of copper(II) sulfate.

3. How could this reaction relate to real-world applications, like airbags?

- **Answer:** In airbags, chemical reactions produce gases, but the presence of water or hydrates could affect the reaction's outcome.

**AI Exploration:**

- Use an AI tool like ChatGPT to ask: \*"What are some examples of hydrates used in everyday life?"\*

- Discuss how hydrates are used in products like desiccants (drying agents) or construction materials.

---

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

### # Prior Knowledge:

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

- Review the concept of chemical formulas and how they represent the composition of a compound.

### # Real-World Connection:

- Hydrates are used in many everyday products. For example, plaster of Paris (used in casts and molds) is made by heating gypsum, a hydrate, to remove water.

### # Background Information:

- Hydrates are compounds that contain water molecules chemically bonded to them.

- The water in a hydrate is not "free" water; it is part of the compound's structure.

- When heated, hydrates lose their water molecules and become "anhydrous."

### # Key Concepts:

1. **Hydrate Formulas:**

- A hydrate's formula shows the compound and the number of water molecules.

- Example: CuSO₄·5H₂O means copper(II) sulfate has 5 water molecules for every formula unit.

2. **Greek Prefixes:**

- Mono- = 1, Di- = 2, Tri- = 3, Tetra- = 4, Penta- = 5, etc.

- These prefixes help identify the number of water molecules in a hydrate.

3. **Percent by Mass of Water in a Hydrate:**

- The percent by mass of water is calculated using the formula:

\[

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

\]

### # Interactive Note:

- Ask: \*Why do you think hydrates are important in industries like medicine or construction?\*

- Example: Hydrates in cement help it set and harden.

---

### Transition to "Explore" Phase:

- With this foundational knowledge, explore how to calculate the percent by mass of water in a hydrate and predict the outcome of reactions involving hydrates.

# Lesson 4: Hydrates – Their Formulas and Reactions

---

## Introduction: What Are Hydrates?

Have you ever left salt or sugar out in a humid room and noticed it clumping together? That’s because water in the air can stick to certain substances. Some compounds, like salts, can actually trap water molecules as part of their structure. These are called **hydrates**.

Hydrates are compounds that contain water molecules within their crystal structure. The water isn’t just sitting there—it’s chemically bonded to the compound. For example, Epsom salt, which you might use in a bath, is a hydrate. Its chemical formula is **MgSO₄·7H₂O**, meaning it contains magnesium sulfate and seven water molecules.

But what happens when you heat a hydrate? The water can be removed, leaving behind an **anhydrous** (water-free) compound. This process is called **dehydration**. Understanding hydrates and how they react is important in chemistry, especially when calculating the percent of water in a compound or predicting the outcome of chemical reactions.

---

## Section 1: Hydrate Formulas and Naming Them

### What Does a Hydrate Formula Look Like?

The formula for a hydrate shows two parts:

1. The **anhydrous compound** (the part without water).

2. The number of water molecules attached, written as **·nH₂O**, where "n" is the number of water molecules.

For example:

- **CuSO₄·5H₂O** = Copper(II) sulfate pentahydrate

- This means for every one unit of copper(II) sulfate, there are five water molecules attached.

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

- This means for every one unit of sodium carbonate, there are ten water molecules.

### Naming Hydrates

To name hydrates, we use **Greek prefixes** to indicate the number of water molecules:

- Mono = 1

- Di = 2

- Tri = 3

- Tetra = 4

- Penta = 5

- Hexa = 6

- Hepta = 7

- Octa = 8

- Nona = 9

- Deca = 10

For example:

- **CaCl₂·2H₂O** = Calcium chloride dihydrate

- **Ba(OH)₂·8H₂O** = Barium hydroxide octahydrate

---

### Sample Problem 1: Naming a Hydrate

**Question:** What is the name of the hydrate with the formula FeCl₃·6H₂O?

**Solution:**

1. Identify the anhydrous compound: FeCl₃ = Iron(III) chloride.

2. Count the water molecules: 6 = Hexa.

3. Combine the two: Iron(III) chloride hexahydrate.

**Answer:** Iron(III) chloride hexahydrate

---

### Practice Question 1

**What is the name of the hydrate with the formula MgSO₄·7H₂O?**

(Answer: Magnesium sulfate heptahydrate)

---

## Section 2: Percent by Mass of Water in a Hydrate

Hydrates are made up of both the anhydrous compound and water. To calculate the **percent by mass of water**, we need to figure out how much of the hydrate’s total mass comes from water.

### Formula for Percent by Mass of Water:

\[

\text{Percent by mass of water} = \left( \frac{\text{Mass of water}}{\text{Mass of hydrate}} \right) \times 100

\]

### Steps to Calculate Percent by Mass of Water:

1. Find the molar mass of the entire hydrate (anhydrous compound + water).

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

3. Use the formula above to calculate the percent by mass.

---

### Sample Problem 2: Percent by Mass of Water

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

**Solution:**

1. Find the molar mass of CuSO₄·5H₂O:

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

- 5H₂O = 5 × [2(1.01) + 16.00] = 90.10 g/mol

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

2. Find the mass of water:

- Mass of water = 90.10 g/mol

3. Calculate the percent by mass of water:

\[

\text{Percent by mass of water} = \left( \frac{90.10}{249.72} \right) \times 100 = 36.08\%

\]

**Answer:** The percent by mass of water is **36.08%**.

---

### Practice Question 2

**What is the percent by mass of water in BaCl₂·2H₂O?**

(Answer: 14.75%)

---

## Section 3: Reactions Involving Hydrates

### What Happens When You Heat a Hydrate?

When you heat a hydrate, the water molecules are released as steam, leaving behind the anhydrous compound. This is a decomposition reaction. For example:

\[

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

\]

The blue crystals of copper(II) sulfate pentahydrate turn into a white powder (anhydrous copper(II) sulfate) when heated.

---

### Sample Problem 3: Predicting Products

**Question:** What are the products when heating MgSO₄·7H₂O?

**Solution:**

1. Identify the anhydrous compound: MgSO₄.

2. Count the water molecules: 7.

3. Write the reaction:

\[

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

\]

**Answer:** The products are **MgSO₄** and **7H₂O**.

---

### Practice Question 3

**What are the products when heating CaCl₂·2H₂O?**

(Answer: CaCl₂ and 2H₂O)

---

## Section 4: Percent Yield of Reactions Involving Hydrates

In real-world experiments, the amount of product you get from a reaction is often less than what you calculated. This is called the **percent yield**.

### Formula for Percent Yield:

\[

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

\]

---

### Sample Problem 4: Percent Yield

**Question:** A student heats 10.0 g of CuSO₄·5H₂O and collects 6.4 g of anhydrous CuSO₄. What is the percent yield?

**Solution:**

1. Find the theoretical yield of CuSO₄:

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

- Molar mass of CuSO₄ = 159.62 g/mol

- Ratio of CuSO₄ to CuSO₄·5H₂O = 159.62 / 249.72 = 0.639

- Theoretical yield = 10.0 g × 0.639 = 6.39 g

2. Calculate the percent yield:

\[

\text{Percent yield} = \left( \frac{6.4}{6.39} \right) \times 100 = 100.16\%

\]

**Answer:** The percent yield is **100.16%** (slightly above 100% due to rounding).

---

### Practice Question 4

**A student heats 12.0 g of BaCl₂·2H₂O and collects 10.0 g of anhydrous BaCl₂. What is the percent yield?**

(Answer: 95.2%)

---

## Progress Check: Scaffolded Questions

### Question 1: Basic Recall

**What is the formula for a hydrate that contains calcium chloride and two water molecules?**

(Answer: CaCl₂·2H₂O)

---

### Question 2: Application

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

(Answer: 62.93%)

---

### Question 3: Analysis

**If a student heats 15.0 g of MgSO₄·7H₂O and collects 7.5 g of anhydrous MgSO₄, what is the percent yield?**

(Answer: 100%)

---

By understanding hydrates, their formulas, and their reactions, we can better predict and analyze chemical processes. Hydrates play an important role in real-world applications, from industrial chemistry to everyday products. Keep practicing, and you’ll master these concepts in no time!

# Lesson 4: Hydrates - Their Formulas and Reactions

## Introduction to Hydrates

Have you ever noticed how some substances seem to "trap" water inside them? These substances are called **hydrates**. A hydrate is a compound that has water molecules chemically bonded to it. These water molecules are not just sitting there—they are an essential part of the compound's structure. Hydrates are common in nature and in the lab, and they play a big role in many chemical reactions.

For example, have you ever seen those small silica gel packets that come in new shoes or bags? They often say "Do Not Eat" on them. These packets absorb water to keep things dry. Silica gel is an example of a substance that can "trap" water, forming a hydrate.

In this lesson, we’ll explore what hydrates are, how to calculate the amount of water in them, and how they behave in chemical reactions. By the end of this lesson, you’ll be able to:

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

- Predict the products of reactions involving hydrates.

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

---

## What Are Hydrates?

### Definition and Structure

A **hydrate** is a compound that contains water molecules within its crystal structure. These water molecules are chemically bonded to the compound. For example, copper(II) sulfate pentahydrate has the formula **CuSO₄·5H₂O**. This means that for every one unit of copper(II) sulfate, there are five water molecules attached to it.

The water in a hydrate is called **water of hydration**. When the water is removed (usually by heating), the compound becomes **anhydrous**, which means "without water." For example:

**CuSO₄·5H₂O (hydrated copper(II) sulfate) → CuSO₄ (anhydrous copper(II) sulfate) + 5H₂O**

### Greek Prefixes in Hydrate Formulas

To describe how many water molecules are in a hydrate, we use **Greek prefixes**:

- Mono- (1)

- Di- (2)

- Tri- (3)

- Tetra- (4)

- Penta- (5)

- Hexa- (6)

- Hepta- (7)

- Octa- (8)

- Nona- (9)

- Deca- (10)

For example:

- **Na₂CO₃·10H₂O** is sodium carbonate decahydrate (10 water molecules).

- **MgSO₄·7H₂O** is magnesium sulfate heptahydrate (7 water molecules).

---

## How to Calculate the Percent by Mass of Water in a Hydrate

One important property of hydrates is the **percent by mass of water**. This tells us how much of the hydrate's mass comes from water. To calculate it, follow these steps:

### Step-by-Step Calculation

1. **Find the molar mass of the hydrate.** Add up the masses of all the atoms in the compound, including the water molecules.

2. **Find the total mass of the water.** Multiply the number of water molecules by the molar mass of water (H₂O = 18.02 g/mol).

3. **Divide the mass of water by the total molar mass of the hydrate.** Multiply by 100 to get the percentage.

### Example Problem

**Problem:** What is the percent by mass of water in copper(II) sulfate pentahydrate (**CuSO₄·5H₂O**)?

**Solution:**

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

Molar mass of 5H₂O = 5 × 18.02 = 90.10 g/mol

Total molar mass of CuSO₄·5H₂O = 159.62 + 90.10 = 249.72 g/mol

2. Mass of water = 90.10 g/mol

3. Percent by mass of water = (90.10 / 249.72) × 100 = **36.08%**

So, water makes up 36.08% of the mass of copper(II) sulfate pentahydrate.

---

### Practice Question

**Question:** What is the percent by mass of water in magnesium sulfate heptahydrate (**MgSO₄·7H₂O**)?

(\*Hint: Molar mass of MgSO₄ = 120.37 g/mol; molar mass of H₂O = 18.02 g/mol\*)

**Answer:**

Molar mass of 7H₂O = 7 × 18.02 = 126.14 g/mol

Total molar mass of MgSO₄·7H₂O = 120.37 + 126.14 = 246.51 g/mol

Percent by mass of water = (126.14 / 246.51) × 100 = **51.18%**

---

## Reactions Involving Hydrates

### Dehydration Reactions

When hydrates are heated, they lose their water of hydration. This is called a **dehydration reaction**. For example:

**CaCl₂·2H₂O → CaCl₂ + 2H₂O**

In this reaction, calcium chloride dihydrate loses its two water molecules when heated, becoming anhydrous calcium chloride.

### Predicting Products of Dehydration

To predict the products of a dehydration reaction:

1. Write the formula of the hydrate.

2. Remove the water molecules (H₂O) and write them as a separate product.

3. Write the formula of the anhydrous compound.

---

### Sample Problem: Predicting Products

**Problem:** What are the products when barium hydroxide octahydrate (**Ba(OH)₂·8H₂O**) is heated?

**Solution:**

1. Write the formula of the hydrate: **Ba(OH)₂·8H₂O**

2. Remove the water: **Ba(OH)₂·8H₂O → Ba(OH)₂ + 8H₂O**

3. Products are anhydrous barium hydroxide (**Ba(OH)₂**) and water (**H₂O**).

---

### Practice Question

**Question:** What are the products when sodium carbonate decahydrate (**Na₂CO₃·10H₂O**) is heated?

**Answer:** **Na₂CO₃·10H₂O → Na₂CO₃ + 10H₂O**

---

## Factors Affecting Percent Yield of Reactions

In the lab, reactions don’t always go perfectly. The **percent yield** tells us how much product we actually get compared to how much we expected. For reactions involving hydrates, several factors can affect the percent yield:

1. **Incomplete Reaction:** Not all of the hydrate may decompose.

2. **Loss of Product:** Some of the water or compound may be lost during heating.

3. **Impurities:** The hydrate may contain impurities that affect the reaction.

---

### Sample Problem: Percent Yield

**Problem:** A student heats 5.00 g of copper(II) sulfate pentahydrate (**CuSO₄·5H₂O**) and collects 3.20 g of anhydrous copper(II) sulfate (**CuSO₄**). What is the percent yield?

**Solution:**

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

Molar mass of CuSO₄ = 159.62 g/mol

2. Theoretical yield of CuSO₄:

(159.62 / 249.72) × 5.00 g = 3.20 g

3. Percent yield = (Actual yield / Theoretical yield) × 100

Percent yield = (3.20 / 3.20) × 100 = **100%**

---

### Practice Question

**Question:** A student heats 10.00 g of magnesium sulfate heptahydrate (**MgSO₄·7H₂O**) and collects 4.80 g of anhydrous magnesium sulfate (**MgSO₄**). What is the percent yield?

(\*Hint: Molar mass of MgSO₄·7H₂O = 246.51 g/mol; molar mass of MgSO₄ = 120.37 g/mol\*)

**Answer:** Percent yield = **96.04%**

---

## Progress Check: Scaffolded Questions

1. **Basic:** What is a hydrate?

**Answer:** A hydrate is a compound that contains water molecules chemically bonded to it.

2. **Intermediate:** What is the percent by mass of water in sodium carbonate decahydrate (**Na₂CO₃·10H₂O**)?

**Answer:** 62.93%

3. **Advanced:** A student heats 12.00 g of barium hydroxide octahydrate (**Ba(OH)₂·8H₂O**) and collects 6.00 g of anhydrous barium hydroxide (**Ba(OH)₂**). What is the percent yield?

**Answer:** 85.71%

---

By the end of this lesson, you should feel confident calculating the percent by mass of water in a hydrate, predicting the products of reactions involving hydrates, and analyzing factors that affect percent yield. Hydrates may seem simple, but they are key players in many chemical reactions that impact our daily lives!