# Unit: Unit 3: Chemical Reactions and Stoichiometry

## Chapter: Chapter 10: Stoichiometry

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

### 1. Big Idea:

The water molecules in hydrates are part of their structure, and understanding their formulas helps predict how these compounds behave in chemical reactions.

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### 2. Essential Questions:

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

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### 3. Phenomenon-Based Learning:

### # Unit Phenomenon:

How can chemical reactions help improve safety features?

### # 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 is a tricky substance, and it is often involved in many chemical reactions. Sometimes water stands by itself in a reaction, but other times it is part of other substances, integrating into their formula as hydrates. How do hydrates affect a chemical reaction? How should they be counted?

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### 4. Vocabulary:

- **Hydrates**: Compounds that contain water molecules as part of their structure, represented in their chemical formulas.

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

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

- **Hydrate formula**: The complete formula of a hydrate, showing both the compound and its water molecules (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):

### # Hands-On Task: Cracking the Mystery of Hydrates

Materials:

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

- A heat-safe dish or aluminum foil

- A source of heat (e.g., Bunsen burner, candle, or stove)

- Kitchen scale (optional)

**Instructions**:

1. Observe a small sample of Epsom salt. Note its appearance—does it look like a dry powder?

2. Gently heat a teaspoon of the salt in a heat-safe dish for 1-2 minutes. Watch carefully as it heats. What happens?

3. Let the salt cool, then observe the new appearance of the compound. Compare it to the original.

**Discussion Questions**:

- What change did you notice in the appearance of the salt?

- Why do you think heating caused this change?

- How could you test if water was part of the original compound?

**Answers**:

- The shiny or crystalline appearance of the Epsom salt may fade as the water molecules leave during heating.

- Heating removes the water from the hydrate, leaving behind the anhydrous compound.

- You could weigh the salt before and after heating to measure the mass of water lost.

### # AI Integration:

Using an AI tool like ChatGPT or an online chemistry database, search for the formula of Epsom salt. Ask:

- "What is the chemical formula of magnesium sulfate heptahydrate?"

- "What happens when hydrates are heated?"

Encourage follow-up questions like, "Why do hydrates lose water when heated?"

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

### # Connecting Prior Knowledge:

- Recall how water is essential in everyday life and reactions. For example, in 7th grade, mixtures of salt and water were discussed. Now, think about how water can bind to certain compounds.

- In 8th grade, chemical formulas like H₂O and NaCl were introduced. Hydrates combine these ideas: they include water molecules in their structure.

### # Real-World Link:

Did you know that the white powder used to keep silica gel packets dry contains an anhydrous compound? When exposed to air, it absorbs moisture and forms a hydrate. This same process occurs in products like concrete and plaster when they set and harden.

### # Background Information:

Hydrates are a special type of compound where water molecules are chemically bonded to the compound. These water molecules are not just "wetting" the compound; they’re part of its structure. For example, copper(II) sulfate pentahydrate (CuSO₄·5H₂O) looks blue because of the water molecules in it. When heated, these water molecules evaporate, leaving an anhydrous (water-free) compound that’s white.

### # Interactive Notes:

- Key fact: The dot (·) in hydrate formulas separates the compound and the water (e.g., CuSO₄·5H₂O means 1 part CuSO₄ and 5 parts H₂O).

- Practice question: If Na₂CO₃·10H₂O is a hydrate, how many water molecules are in it?

**Answer: 10.**

### # Scaffolded Question:

- Why might the mass of a hydrate decrease after heating?

**Answer: The lost mass comes from the water that was part of the compound being evaporated.**

# Lesson 4: Hydrates – Their Formulas and Reactions

### Introduction

Welcome to Lesson 4 of our chemistry journey! Today, we’re diving into the fascinating world of hydrates. These are special substances that have water as part of their structure—not just mixed in, but locked into their very formula! Hydrates play a major role in many chemical reactions, and understanding them is key to predicting how reactions work, especially when water is involved.

Let’s tie this to the phenomenon we’ve been discussing: safety features in cars. Airbags contain chemicals that react to produce gas in a split second. If any of these chemicals were hydrates, the water locked in their structure could significantly affect the reaction. For example, the water might change the amount of gas produced or even slow the reaction down.

By the end of this lesson, you’ll know how to:

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

2. Predict the products of reactions involving hydrates.

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

So, let’s explore what hydrates are and why they’re so important for both chemistry and safety.

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### What Are Hydrates?

Hydrates are special compounds that include water molecules as part of their structure. The water isn’t just floating around randomly; it’s bonded to the compound in a specific ratio. This is what makes hydrates unique.

For example, Epsom salt, which many people use to relax sore muscles, is a hydrate. Its chemical formula is **MgSO₄·7H₂O**. This means that for every one magnesium sulfate (MgSO₄) unit, there are seven water (H₂O) molecules attached to it.

### # Hydrate Formula

The formula of a hydrate has two parts:

1. **The main substance** (called the anhydrous compound, which means "without water").

2. **The water molecules** (written with a dot and a number showing how many water molecules are attached).

For example:

- **CuSO₄·5H₂O** is copper(II) sulfate pentahydrate. The "penta-" prefix means five water molecules are attached.

- **Na₂CO₃·10H₂O** is sodium carbonate decahydrate. The "deca-" prefix means ten water molecules are attached.

> **Vocabulary Check**

> - **Anhydrous formula**: The part of the hydrate that does NOT include water (e.g., CuSO₄ in CuSO₄·5H₂O).

> - **Greek prefix**: A prefix used to show the number of water molecules in a hydrate (e.g., mono- for 1, di- for 2, tri- for 3, etc.).

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### Calculating 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 total mass is made up of water. It’s a key concept when working with hydrates in chemical reactions.

### # Example Problem: Finding Percent by Mass of Water

Let’s take the hydrate **CuSO₄·5H₂O** (copper(II) sulfate pentahydrate) and calculate the percent by mass of water.

### Step 1: Find the molar masses of all parts.

- Molar mass of CuSO₄ (anhydrous compound):

Cu = 63.55 g/mol

S = 32.07 g/mol

O₄ = 4 × 16.00 g/mol = 64.00 g/mol

**Total = 63.55 + 32.07 + 64.00 = 159.62 g/mol**

- Molar mass of 5H₂O (water molecules):

H₂O = 2 × 1.01 g/mol + 16.00 g/mol = 18.02 g/mol

5H₂O = 5 × 18.02 g/mol = 90.10 g/mol

- Total molar mass of CuSO₄·5H₂O:

159.62 g/mol + 90.10 g/mol = **249.72 g/mol**

### Step 2: Calculate the percent by mass of water.

\[

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

\]

\[

= \left( \frac{90.10}{249.72} \right) \times 100 = 36.07\%

\]

So, **36.07% of the mass of CuSO₄·5H₂O is water**.

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### # Practice Question 1

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

> **Answer**:

1. Molar mass of Na₂CO₃: 105.99 g/mol

2. Molar mass of 10H₂O: 10 × 18.02 g/mol = 180.20 g/mol

3. Total molar mass: 105.99 + 180.20 = 286.19 g/mol

4. Percent by mass of water:

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= \left( \frac{180.20}{286.19} \right) \times 100 = 62.96\%

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### Reactions Involving Hydrates

Hydrates can either **release water** or **react with water**, depending on the situation. When you heat a hydrate, it loses its water and becomes "anhydrous."

### # Example Reaction: Heating a Hydrate

When you heat **CuSO₄·5H₂O**, it loses its water and becomes anhydrous copper(II) sulfate (CuSO₄). The reaction looks like this:

\[

\text{CuSO₄·5H₂O (s)} \xrightarrow{\text{heat}} \text{CuSO₄ (s)} + 5\text{H₂O (g)}

\]

> **Tip**: The dot in the formula doesn’t mean multiplication—it just shows how the water is attached to the compound.

### # Practice Question 2

What product forms when you heat **BaCl₂·2H₂O** (barium chloride dihydrate)? Write the equation.

> **Answer**:

\[

\text{BaCl₂·2H₂O (s)} \xrightarrow{\text{heat}} \text{BaCl₂ (s)} + 2\text{H₂O (g)}

\]

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### Factors Affecting Percent Yield

In real-world reactions, it’s rare to get 100% of the product you calculated. This difference is called the **percent yield**. When hydrates are involved, the water content can affect the reaction’s efficiency.

**Factors include:**

1. **Impurities in the hydrate**: If the hydrate isn’t pure, the reaction might not produce the expected results.

2. **Incomplete reaction**: Not all the hydrate may react completely.

3. **Loss of water during handling**: If the hydrate starts losing water before the reaction, the results can be affected.

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### # Practice Question 3

A hydrate was supposed to produce 10.0 g of an anhydrous compound, but only 8.5 g was collected. What was the percent yield?

> **Answer**:

\[

\text{Percent yield} = \left( \frac{\text{actual yield}}{\text{theoretical yield}} \right) \times 100

\]

\[

= \left( \frac{8.5}{10.0} \right) \times 100 = 85.0\%

\]

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### Real-World Connection

Let’s go back to airbags for a moment. Imagine if one of the chemicals inside an airbag was a hydrate. The water content would change how much gas is produced when the airbag deploys. If the reaction doesn’t produce enough gas, the airbag won’t inflate properly, which could lead to serious injuries. That’s why manufacturers need to carefully control the chemicals they use, including any hydrates.

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### Progress Check: Evaluate Your Understanding

1. What is the formula for a hydrate that has 3 water molecules attached to calcium chloride (CaCl₂)?

- **Answer**: **CaCl₂·3H₂O**

2. Calculate the percent by mass of water in MgSO₄·7H₂O. (Hint: Molar mass of MgSO₄ is 120.37 g/mol, and molar mass of 7H₂O is 126.14 g/mol.)

- **Answer**:

Total molar mass = 120.37 + 126.14 = 246.51 g/mol

Percent by mass of water:

\[

= \left( \frac{126.14}{246.51} \right) \times 100 = 51.19\%

\]

3. If a hydrate loses water when heated, what type of compound is left behind?

- **Answer**: The **anhydrous compound**.

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### Summary

Hydrates are important compounds with water locked into their structure. In this lesson, we learned how to:

- Identify hydrates and write their formulas.

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

- Predict what happens when hydrates are heated.

- Analyze how hydrates can affect the percent yield of a reaction.

We also explored how this connects to real-world safety features, like airbags. Hydrates might seem simple, but they have a huge impact on the reactions and technologies that keep us safe!

### 9. Elaborate (Power Up)

Here’s an opportunity to deepen your understanding of chemistry concepts! Try these questions and mini-tasks:

**Open-Ended Questions:**

1. Why do you think the periodic table is organized the way it is? How does its layout help scientists predict the properties of an element?

**Answer:** The periodic table is organized by increasing atomic number, which corresponds to the number of protons in an atom. The layout helps scientists see trends in element properties like reactivity, electronegativity, and atomic size. Elements in the same group (vertical columns) have similar chemical properties because they have the same number of valence electrons.

2. Imagine you are designing a new element. What might its properties be, and where on the periodic table would you place it?

**Answer:** Students might suggest properties based on trends (e.g., if placed in Group 1, it might be highly reactive with water like other alkali metals). Its atomic number would place it in a specific location, determining its reactivity, bonding behavior, and other characteristics.

**Mini-Task:**

Create a color-coded diagram of the periodic table that highlights:

- Metals, nonmetals, and metalloids.

- Groups like alkali metals, halogens, and noble gases.

- Trends in atomic size or reactivity.

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### 10. Final Evaluation

**Debate Question:**

“Should we invest more in finding synthetic elements, or should we focus on studying naturally occurring ones?”

**Discussion Points:**

1. Synthetic elements expand our knowledge of chemistry and physics but are often unstable and hard to use.

2. Naturally occurring elements are more abundant and practical for everyday applications, but their study may have limitations for discovering new properties.

**Discussion Paragraph:**

Synthetic elements offer a glimpse into the unknown, allowing scientists to push the boundaries of chemistry and explore new possibilities. However, they are often unstable, existing only for fractions of a second. On the other hand, naturally occurring elements are the foundation of the materials we use and study every day. Should resources and time be split evenly between these two areas, or should priorities shift toward one?

**MCQ Related to Debate:**

What is one key challenge of working with synthetic elements?

a) They are easy to find in nature.

b) They are unstable and decay quickly.

c) Their properties are identical to naturally occurring elements.

d) They are commonly found in the atmosphere.

**Correct Answer:** b) They are unstable and decay quickly.

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**Assessment Questions**

**ACT-Style Multiple Choice Questions:**

1. Which of the following elements is a noble gas?

a) Sodium (Na)

b) Neon (Ne)

c) Magnesium (Mg)

d) Iron (Fe)

**Answer:** b) Neon (Ne)

**Explanation:** Noble gases are in Group 18 of the periodic table and are known for their stability and lack of reactivity. Neon is one of them.

2. What determines the reactivity of alkali metals?

a) Their number of neutrons.

b) Their position in the periodic table.

c) Their single valence electron.

d) Their atomic number being even.

**Answer:** c) Their single valence electron.

**Explanation:** Alkali metals have one valence electron, making them highly reactive as they seek to lose that electron and achieve a stable electron configuration.

3. Which of the following correctly represents a trend in the periodic table?

a) Atomic size increases as you move from top to bottom in a group.

b) Electronegativity increases as you move down a group.

c) Reactivity decreases as you move from left to right across a period for metals.

d) Noble gases are the most reactive elements.

**Answer:** a) Atomic size increases as you move from top to bottom in a group.

**Explanation:** Atomic size increases because additional electron shells are added as you move down a group, increasing the distance from the nucleus.

4. Which family of elements is the most reactive group of nonmetals?

a) Alkali metals

b) Halogens

c) Noble gases

d) Transition metals

**Answer:** b) Halogens

**Explanation:** Halogens are highly reactive nonmetals because they need just one electron to complete their valence shell.

**Long-Answer Questions:**

1. Explain why elements in the same group have similar chemical properties.

**Answer:** Elements in the same group have the same number of valence electrons, which determines how they bond and react. For example, Group 1 elements all have one valence electron, making them highly reactive and prone to losing that electron in reactions.

2. Describe two trends that occur as you move across a period in the periodic table. Provide examples.

**Answer:** As you move across a period from left to right:

- Electronegativity increases because atoms have a stronger pull on electrons due to an increasing nuclear charge. For example, fluorine is more electronegative than lithium.

- Atomic radius decreases because the increasing number of protons pulls electrons closer to the nucleus. For example, carbon has a smaller atomic radius than sodium.

3. Compare and contrast the reactivity of alkali metals and noble gases.

**Answer:** Alkali metals are highly reactive because they have one valence electron that they readily lose to form positive ions. Noble gases, on the other hand, are non-reactive because they have a full valence shell, making them stable and unlikely to form bonds.

4. Predict the properties of an undiscovered element in Group 2, Period 7 of the periodic table.

**Answer:** This element would likely have 2 valence electrons, making it similar to other alkaline earth metals. It would be reactive (though less so than Group 1 metals), have a larger atomic radius than calcium or magnesium, and likely form +2 ions. Being in Period 7, it might also be radioactive.

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### 11. Extend (Beyond the Lesson)

**Real-World Applications:**

1. Research how the properties of elements like silicon (semiconductor) have contributed to advancements in technology like computers and solar panels. Write a short report about your findings.

2. Create a comic strip or infographic explaining how the periodic table helps chemists predict the behavior of unknown substances.

**Ongoing Activities:**

- For one week, identify elements in common household items (e.g., aluminum in foil, chlorine in bleach). Keep a labeled journal.

- Look into how synthetic elements like americium are used in smoke detectors, and discuss their importance despite their instability.

**Hint for Future Learning:**

Next, we’ll explore chemical bonding, where you’ll learn how elements interact to form compounds. Start thinking about why some elements easily combine with others while some don’t—valence electrons are the key!