### 1. Big Idea:

Hydrates are compounds that include water molecules within their structure, and understanding their formulas and reactions helps explain how water interacts with certain substances in chemical reactions.

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### 2. Essential Questions:

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

- Hydrates form when water molecules are incorporated into a substance's crystal structure. Their composition can be determined by calculating the ratio of water to the rest of the compound, often expressed in a hydrate's chemical formula.

- For example, in copper(II) sulfate pentahydrate (CuSO₄·5H₂O), five water molecules are combined with one formula unit of copper(II) sulfate.

2. **How do hydrates affect chemical reactions?**

- Hydrates release their water of crystallization when heated, which can change their mass and influence the chemical reaction's products. For example, heating gypsum (CaSO₄·2H₂O) produces Plaster of Paris (CaSO₄·0.5H₂O) and water vapor.

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### 3. Phenomenon-Based Learning:

**Unit Phenomenon:**

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

**Background:**

Car accidents are a major cause of injuries and fatalities worldwide. Road safety is a critical concern implemented by governments to reduce accidents. Cars manufacturers also aim at reducing risks by including two major safety features: seat belts and airbags. Front airbags reduce driver fatalities in frontal crashes by 29% and fatalities of front-seat passengers aged 13 and older by 32%; side airbags that protect the head reduce a car driver’s risk of death in driver-side crashes by 37% and an SUV driver’s risk by 52%. Overall, airbags can reduce passenger injuries by 50% in a car accident. In the event of a car crash, sensors trigger the airbags to deploy rapidly to cushion and protect passengers. The cushion is provided by gas that is rapidly released from a chemical reaction inside the airbag. The airbag inflates due to the gas from the chemical reaction. But the products of the chemical reaction should also be safe for passengers. For example, excess sodium metal can react violently with moisture in the air.

**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, like it integrates their formula! These are called hydrates. How would hydrates affect a chemical reaction? How should they be counted?

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### 4. Vocabulary:

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

**Example**: Copper(II) sulfate pentahydrate (CuSO₄·5H₂O).

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

**Example**: CuSO₄ is the anhydrous form of CuSO₄·5H₂O.

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

**Example**: “Penta-” in pentahydrate means five water molecules.

- **Hydrate Formula:** A formula that shows the ratio of water molecules to the compound.

**Example**: Na₂CO₃·10H₂O (sodium carbonate decahydrate).

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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 Hydrate Code!"**

Explore the relationship between hydrates and water using easily available materials.

**Materials:**

- Epsom salt (MgSO₄·7H₂O), a small weighing scale, a candle, a lighter, and a metal spoon.

**Instructions:**

1. Weigh a small amount (~5g) of Epsom salt on the scale. Record the mass.

2. Place the Epsom salt into the metal spoon.

3. Gently heat the spoon over the candle flame. Observe any changes (e.g., water droplets forming and salt turning white).

4. Reweigh the substance after heating and compare the final mass to the original mass.

**Questions:**

1. What caused the mass of the substance to decrease after heating?

**Answer:** The mass decreased because the water of crystallization was removed, leaving behind the anhydrous form.

2. How many water molecules make up the hydrate MgSO₄·7H₂O? How might this affect its use in reactions that involve heat?

**Answer:** Seven water molecules. It would release those molecules when heated, which could change the mass and reaction conditions.

**AI Tool Task:** Use an AI chatbot (like ChatGPT) to search for other real-life uses of hydrates. Ask: **“How is calcium sulfate hydrate (gypsum) used in construction?”**

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

**Recall Prior Knowledge:**

- From earlier studies, recall what happens when substances are heated. For example, heating sugar caused it to melt and decompose during a previous experiment.

- Relate to the law of conservation of mass—they saw mass "disappear" as gas during heating experiments but understood it was still conserved.

**Real-World Example:**

- Plaster of Paris (used in casts and moldings) is made by heating gypsum (CaSO₄·2H₂O) to remove water, forming CaSO₄·0.5H₂O. When mixed with water, the reaction reverses, reforming the solid gypsum. This process makes it ideal for quickly hardening materials.

**Interactive Notes:**

1. Hydrates are like “water-packed” compounds where water molecules are locked in a specific ratio within the crystal.

2. Heating hydrates releases water, turning them into their anhydrous form.

3. You can calculate the percent by mass of water in a hydrate using the formula:

\[

\% \text{water by mass} = \frac{\text{mass of water}}{\text{total mass of hydrate}} \times 100

\]

**Scaffolded Questions**

- What is the formula for a hydrate that contains 1 magnesium sulfate unit (MgSO₄) and 7 water molecules?

**Answer:** MgSO₄·7H₂O.

- If 5g of CuSO₄·5H₂O loses 1.8g of water when heated, what is the mass of the anhydrous form?

**Answer: 3.2g (5g – 1.8g).**

This foundational understanding prepares for exploring hydrate reactions and calculations in the next phases.

# Lesson 4: Hydrates — Their Formulas and Reactions

## Introduction

Have you ever left a packet of salt or sugar open on a humid day? If you have, you might have noticed that it starts to clump together. This happens because moisture in the air gets trapped by the salt or sugar. In chemistry, some substances not only absorb water but even make it part of their structure. These substances are called **hydrates**. Hydrates lock water molecules into their chemical formula, and this inclusion of water can affect how the compound behaves in chemical reactions.

In this lesson, we will explore what hydrates are, their formulas, and how they react. We'll also investigate how water, as part of a hydrate, influences percentages, reaction yields, and the products formed during a reaction. Finally, you'll get hands-on with problems and examples that connect hydrates to real-world phenomena.

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## Section 1: What Are Hydrates?

### What is a Hydrate?

A **hydrate** is a compound that contains water molecules as part of its crystal structure. These water molecules are not just "on" the compound; they are **inside** it, held in place by chemical forces. The water in a hydrate is called **water of hydration**, and it plays an important role in the compound's structure and properties.

Let’s look at an example:

- **Copper(II) sulfate pentahydrate,** with the formula \( \text{CuSO}\_4 \cdot 5\text{H}\_2\text{O} \), is a bright blue compound. The "5H\(\_2\)O" means that for every molecule of copper(II) sulfate (\( \text{CuSO}\_4 \)), there are five water molecules attached.

If you remove the water by heating, the compound changes. Without the water, it becomes a white powder called **anhydrous copper(II) sulfate.**

The term **anhydrous** means "without water." So, hydrates are compounds **with** water, and anhydrous substances are the same compounds **without** water.

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### Where Are Hydrates Found in the Real World?

Hydrates are all around us. Some examples include:

- **Epsom salt** (\( \text{MgSO}\_4 \cdot 7\text{H}\_2\text{O} \)): Commonly used in baths to soothe muscles, Epsom salt is a magnesium sulfate hydrate.

- **Gypsum** (\( \text{CaSO}\_4 \cdot 2\text{H}\_2\text{O} \)): Found in drywall, gypsum is a calcium sulfate hydrate.

- **Hand warmers**: In some chemical hand warmers, hydrates like sodium acetate release heat when their water of hydration is removed.

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### Practice Question 1

**Question:** Which of the following is an example of a hydrate?

1. Table salt (\( \text{NaCl} \))

2. Calcium chloride dihydrate (\( \text{CaCl}\_2 \cdot 2\text{H}\_2\text{O} \))

3. Sand (\( \text{SiO}\_2 \))

4. Pure water (\( \text{H}\_2\text{O} \))

**Answer:** The correct answer is **2. Calcium chloride dihydrate**, because it has water molecules included in its formula.

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## Section 2: Hydrate Formulas and Mass Percent of Water

### How Do We Write Hydrate Formulas?

The formula of a hydrate includes two parts:

1. The chemical formula of the main compound.

2. The number of water molecules, written as \( \cdot n\text{H}\_2\text{O} \), where \( n \) is the number of water molecules per formula unit.

For example:

- \( \text{BaCl}\_2 \cdot 2\text{H}\_2\text{O} \): Barium chloride dihydrate (2 molecules of water).

- \( \text{Na}\_2\text{CO}\_3 \cdot 10\text{H}\_2\text{O} \): Sodium carbonate decahydrate (10 molecules of water).

The number \( n \) is always a whole number, and it comes from the ratio of water molecules to the compound in its crystal structure.

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

The **percent by mass of water** in a hydrate tells us what percentage of the compound's weight comes from water. Here’s how to calculate it:

1. Find the **molar mass** of the entire hydrate. This includes the molar mass of the main compound and the water.

2. Divide the total mass of the water molecules by the hydrate's total molar mass.

3. Multiply by 100 to get a percentage.

**Example:**

Let’s calculate the percent by mass of water in \( \text{CuSO}\_4 \cdot 5\text{H}\_2\text{O} \).

1. Molar mass of \( \text{CuSO}\_4 \):

\( 63.55 + 32.07 + (4 \times 16.00) = 159.62 \, \text{g/mol} \).

2. Molar mass of \( 5\text{H}\_2\text{O} \):

\( 5 \times [2(1.01) + 16.00] = 90.10 \, \text{g/mol} \).

3. Total molar mass of \( \text{CuSO}\_4 \cdot 5\text{H}\_2\text{O} \):

\( 159.62 + 90.10 = 249.72 \, \text{g/mol} \).

4. Percent by mass of water:

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

So, water makes up **36.07%** of the compound’s mass.

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### Practice Question 2

**Question:** Calculate the percent by mass of water in sodium carbonate decahydrate (\( \text{Na}\_2\text{CO}\_3 \cdot 10\text{H}\_2\text{O} \)).

**Answer:**

1. Molar mass of \( \text{Na}\_2\text{CO}\_3 \):

\( 2(22.99) + 12.01 + 3(16.00) = 105.99 \, \text{g/mol} \).

2. Molar mass of \( 10\text{H}\_2\text{O} \):

\( 10 \times [2(1.01) + 16.00] = 180.20 \, \text{g/mol} \).

3. Total molar mass:

\( 105.99 + 180.20 = 286.19 \, \text{g/mol} \).

4. Percent by mass of water:

\( \frac{180.20}{286.19} \times 100 = 62.97\% \).

Water makes up **62.97%** of \( \text{Na}\_2\text{CO}\_3 \cdot 10\text{H}\_2\text{O} \)'s mass.

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## Section 3: Reactions Involving Hydrates

### Predicting Products of Hydrate Reactions

When hydrates are heated, they often lose their water molecules in a process called **dehydration**. This leaves behind the anhydrous form of the compound. The reaction can be written as:

\[

\text{Hydrate} \xrightarrow{\text{heat}} \text{Anhydrous compound} + \text{Water vapor}

\]

For example:

\[

\text{CuSO}\_4 \cdot 5\text{H}\_2\text{O} \xrightarrow{\text{heat}} \text{CuSO}\_4 + 5\text{H}\_2\text{O}

\]

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### Factors That Affect Percent Yield of a Reaction

Percent yield measures how much product you actually get compared to how much you theoretically expect. For hydrates, these factors can affect yield:

1. **Incomplete dehydration**: If all water isn’t removed, the final product will weigh more than expected.

2. **Contamination**: Impurities can make the mass of your product inaccurate.

3. **Measurement errors**: Small mistakes in weighing hydrates or heating can affect results.

**Percent Yield Formula:**

\[

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

\]

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### Practice Question 3

**Question:** If 5.00 g of \( \text{CuSO}\_4 \cdot 5\text{H}\_2\text{O} \) is heated and produces 3.20 g of \( \text{CuSO}\_4 \), what is the percent yield?

**Answer:**

1. Theoretical yield is the mass of \( \text{CuSO}\_4 \):

Molar mass of \( \text{CuSO}\_4 \): \( 159.62 \, \text{g/mol} \).

Molar mass of \( \text{CuSO}\_4 \cdot 5\text{H}\_2\text{O} \): \( 249.72 \, \text{g/mol} \).

Ratio of masses: \( \frac{159.62}{249.72} \).

Theoretical yield:

\( 5.00 \, \text{g} \times \frac{159.62}{249.72} = 3.20 \, \text{g} \).

2. Percent yield:

\( \frac{3.20}{3.20} \times 100 = 100\% \).

The percent yield is **100%**.

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## Evaluate (Progress Check)

1. **What is the definition of a hydrate?**

**(Answer: A hydrate is a compound that includes water molecules as part of its crystal structure.)**

2. **What is the percent by mass of water in \( \text{MgSO}\_4 \cdot 7\text{H}\_2\text{O} \)?**

**(Answer: 51.16%)**

3. **Write the products of heating \( \text{BaCl}\_2 \cdot 2\text{H}\_2\text{O} \).**

**(Answer: \( \text{BaCl}\_2 + 2\text{H}\_2\text{O} \))**

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By learning about hydrates, you now understand how water plays a role even in substances that seem dry! From understanding their composition to analyzing their reactions, hydrates teach us how chemistry explains everyday phenomena, including the smart materials used to keep us safe on the road.

### 9. Elaborate (Power Up):

Let’s dive deeper into chemistry by exploring some open-ended questions. These encourage critical thinking and help cement what we’ve learned.

**Open-Ended Questions:**

1. Why do you think some elements readily bond with others, while some prefer to stay on their own (like noble gases)?

- **Answer**: Elements bond to achieve a more stable electronic configuration, often resembling the stability of noble gases with a full outer shell. Noble gases don’t bond easily because they already have this configuration.

2. Can you think of examples in your daily life where chemical reactions are happening? How do these reactions benefit or harm us?

- **Answer**: Examples include cooking (beneficial: food preparation through heat reactions), rusting of metal (harmful: weakens structures), and digestion (beneficial: breaks down food for energy).

3. If you could combine two elements to create a new material, what would you create and why?

- **Answer**: (Example response) By combining carbon (strong bonds) and titanium (lightweight and strong), I could invent a super-strong but lightweight material for spacecrafts.

4. Why is water, H₂O, so essential for life even though it’s a simple molecule?

- **Answer**: Water is a universal solvent, allowing chemical reactions in cells to occur. It also regulates temperature and transports nutrients and waste in living organisms.

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### 10. Progress Check (Final Evaluation)

**Debate Question:**

"Should countries make it mandatory to study chemistry until the end of high school?"

**Discussion Points:**

- Chemistry helps us understand the world (e.g., environmental issues, medicine).

- Not everyone enjoys or finds it necessary for their career.

- Understanding chemistry can improve decision-making in daily life (e.g., recycling, health).

**Paragraph for Debate:**

Chemistry plays a vital role in our daily lives by explaining how substances interact and create the world around us. From developing life-saving medicines to solving environmental challenges, chemistry helps solve global problems. However, not everyone will need chemistry knowledge for their careers, and some find it less enjoyable than other sciences. Should we require everyone to study it until the end of high school, or should students have more freedom to choose?

**MCQ Question:**

Which of the following is NOT a reason why chemistry is important in everyday life?

A. It helps us understand environmental problems.

B. It teaches us how to write essays about history.

C. It explains how medicines work.

D. It helps us make informed decisions about food and safety.

- **Correct Answer**: B. It teaches us how to write essays about history.

- **Explanation**: Chemistry focuses on science, not history skills!

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### # ACT-Style Questions

1. **Question**: Which of the following best describes why noble gases rarely form compounds?

A. They are radioactive.

B. They lack protons in the nucleus.

C. They have a full outer electron shell.

D. They are too heavy to bond.

- **Answer**: C. They have a full outer electron shell.

- **Explanation**: Noble gases are stable on their own because their outer shells are already complete, so they don’t bond easily.

2. **Question**: What is the chemical formula for a compound formed between aluminum (Al) and oxygen (O)?

A. AlO

B. Al₂O

C. Al₂O₃

D. Al₃O₂

- **Answer**: C. Al₂O₃

- **Explanation**: Aluminum forms a +3 charge, and oxygen forms a -2 charge. The charges balance to form Al₂O₃.

3. **Question**: A student adds baking soda (NaHCO₃) to vinegar (CH₃COOH). What gas is released during the reaction?

A. Oxygen

B. Hydrogen

C. Carbon dioxide

D. Nitrogen

- **Answer**: C. Carbon dioxide.

- **Explanation**: The reaction between baking soda and vinegar releases CO₂ gas, creating bubbles.

4. **Question**: Which property of water makes it a good solvent for ionic compounds?

A. It’s a nonpolar molecule.

B. It has a high boiling point.

C. It’s polar and can separate ions.

D. It conducts electricity.

- **Answer**: C. It’s polar and can separate ions.

- **Explanation**: Water’s polarity allows it to attract positive and negative ions, breaking ionic bonds to dissolve substances.

**Long-Answer Questions**

1. **Question**: Explain why atoms form bonds and describe the two main types of chemical bonds.

- **Answer**: Atoms form bonds to become more stable by achieving a full outer electron shell. The two main types are ionic bonds, where electrons are transferred between a metal and nonmetal, and covalent bonds, where electrons are shared between nonmetals.

2. **Question**: Why is understanding the pH scale important in chemistry and daily life? Provide examples.

- **Answer**: The pH scale measures how acidic or basic a substance is. It’s important for everyday tasks like checking soil for gardening, balancing pool water, and controlling acidity in food. For example, stomach acid has a low pH needed for digestion, while baking soda (basic) can neutralize excess acid.

3. **Question**: Describe three ways chemistry contributes to sustainable living.

- **Answer**: Chemistry helps create renewable energy sources (like biofuels), develop biodegradable materials to reduce waste, and design processes that minimize pollution (like green chemistry for cleaning up spills).

4. **Question**: How can you identify a chemical reaction? List at least three signs and provide examples.

- **Answer**: Chemical reactions show signs like color change (e.g., rusting iron), gas production (e.g., vinegar and baking soda), and temperature change (e.g., burning wood). These signs indicate new substances are forming.

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### 11. Extend (Beyond the Lesson)

1. **Task:**

Find three household items (e.g., soap, vinegar, baking soda) and research the chemistry behind them. Write a short description of how each one works, including the type of chemical reaction or property involved.

2. **Real-World Challenge:**

Test the acidity or basicity of common liquids, like lemon juice, soda, or milk, using litmus paper. Compare the results and think about why some liquids are acidic while others are basic.

3. **Reading Suggestion:**

Explore "The Disappearing Spoon" by Sam Kean for fascinating stories about elements in the periodic table and their uses in science and history.

4. **Upcoming Topics Hint:**

Next, we’ll be diving into chemical equations and balancing them. Get ready to explore how chemists ensure that atoms are neither created nor destroyed in reactions!