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

**Unit 3: Chemical Reactions and Stoichiometry**

**Chapter 10: Stoichiometry**

### 1. Big Idea

Chemical formulas sometimes include water as part of a compound, called hydrates. Understanding how hydrates form, their composition, and how they react is an important step in mastering chemical reactions.

### 2. Essential Questions

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

- Hydrates form when water molecules attach to the structure of certain ionic compounds during their crystallization. Their composition can be determined by analyzing the mass of water released when they are heated.

- **Why does water sometimes become part of a chemical formula?**

- Water molecules can interact with ionic compounds due to the forces between polar molecules and ions. These water molecules fit into the crystal lattice structure of the compound, forming a hydrate.

### 3. Phenomenon-Based Learning

### Unit Phenomenon:

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

- **Background:**

Car crashes cause injuries and fatalities around the world. Airbags deploy during accidents to protect passengers using gases produced by chemical reactions. These reactions must be fast, and their products should be safe for passengers. For instance, sodium azide (NaN₃) reacts to release nitrogen gas, which inflates the airbag. However, extra sodium from this reaction can react dangerously with moisture in the air.

### Chapter Phenomenon:

- **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:

- **Phenomenon:** Water is a tricky substance, often involved in chemical reactions. Sometimes water stands alone, but other times it is part of a compound’s chemical structure, forming hydrates. How do hydrates influence chemical reactions? How are hydrates counted in formulas?

### 4. Vocabulary

- **Anhydrous Formula:** The chemical formula of a compound without water molecules attached.

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

- **Hydrates:** Compounds with water molecules integrated into their crystal lattice.

- **Hydrate Formula:** The chemical formula of a hydrate, showing both the compound and the associated water molecules (e.g., CuSO₄·5H₂O).

### 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.

### 6. Engage (Ignite)

**Activity: "Heating a Hydrate"**

**Objective:** Discover how heating a hydrate releases water and observe how this relates to chemical reactions.

### Materials:

- A small amount of epsom salt (MgSO₄·7H₂O) – easily available in pharmacies.

- A balance to measure mass.

- A heat-resistant spoon or small metal container.

- A lighter or candle.

- Safety goggles and gloves.

### Procedure:

1. Measure the mass of a clean, dry spoon or container.

2. Add a small amount of epsom salt to the container and record its total mass (container + epsom salt).

3. Gently heat the container over a candle flame while observing any changes.

4. After a few minutes, let the container cool and measure its final mass.

### Observations:

- **Before heating:** The hydrate is a solid with a crystalline structure.

- **During heating:** Steam is released as water evaporates, and the solid may crumble or turn white.

- **After heating:** The substance left behind is anhydrous magnesium sulfate (MgSO₄).

### Follow-Up Questions:

1. **What happens to the water in the hydrate when it is heated?**

- Answer: The water molecules are released as vapor, leaving the anhydrous compound.

2. **How did the mass change after heating the hydrate? Why?**

- Answer: The mass decreased because water was lost from the hydrate.

3. **How is this process related to safety in car airbags?**

- Answer: In airbags, controlled chemical reactions rapidly produce gases. The absence of excess water or unsafe reactions ensures passenger safety.

**Extension Task:**

Use an AI tool (like a chemical reaction simulator) to predict other hydrates’ behavior when heated. Example tools: ChemCollective or PhET Interactive Simulations.

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

### Relevant Prior Knowledge:

- In grade 7, the concept of water as a polar molecule was introduced, showing how it interacts with ionic compounds (e.g., salt dissolving in water).

- In grade 8, students learned about chemical formulas and how to determine molar mass.

### Real-World Connection:

Epsom salt is used in baths for muscle relaxation, but its effectiveness relies on its hydrate form (MgSO₄·7H₂O). When stored poorly, it can lose water and become less effective!

### Background Information:

Water molecules attach to ionic compounds in a fixed ratio during crystallization, forming hydrates. These are written as **compound·nH₂O**, where “n” is the number of water molecules. Heating removes this water, leaving the anhydrous form.

### Interactive Notes:

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

- **Discussion Prompt:** “How does the prefix ‘penta-’ in pentahydrate relate to the number of water molecules?”

### Scaffolding:

- Ask: What do you think happens to the structure of a hydrate when it loses water?

- Think-Pair-Share: How might hydrates affect the mass of substances in a chemical reaction?

This section lays the foundation for learners to explore formulas and the reactions of hydrates in greater depth.

# Explain:

### Introduction: What Are Hydrates?

Have you ever noticed how certain substances become dry and crumbly after sitting out too long? Or maybe you've seen a crystal that looks shiny because it seems to "hold onto water." These are examples of hydrates! Hydrates are compounds that have water molecules chemically attached to them. But don’t confuse them with wet substances like a soaked sponge—hydrates have water as part of their chemical structure. These water molecules are trapped inside the substance in a specific ratio.

For example, imagine a salt crystal that has water molecules locked inside. In its formula, water isn’t just floating around—it’s written as part of the compound! A good example of this is copper(II) sulfate pentahydrate, with the formula **CuSO₄·5H₂O**. That "·5H₂O" tells us the compound contains five water molecules for every formula unit of copper(II) sulfate.

### Section 1: Understanding Hydrate Formulas

The formula of a hydrate looks a little different from the formulas you may have seen before. It includes two parts:

1. The "main" compound, called the **anhydrous formula** (this tells you what the substance is without water).

2. The water molecules attached to it, shown as a multiple of **H₂O**.

For example:

- **CuSO₄·5H₂O**: This is copper(II) sulfate pentahydrate. The “5” before H₂O means there are five water molecules for every one unit of CuSO₄.

- **MgSO₄·7H₂O**: This is magnesium sulfate heptahydrate. The “7” means seven water molecules are attached.

The Greek prefixes like **mono- (1)**, **di- (2)**, **tri- (3)**, and so on are used to indicate the number of water molecules. Handy, right?

> ⚡ **Real-World Connection**: Epsom salt, which people use in baths to soothe sore muscles, is magnesium sulfate heptahydrate. Without its water, it would just look like a dry powder!

### Solved Sample Problem: Writing Hydrate Formulas

**Problem**: Write the chemical formula for sodium carbonate decahydrate.

1. Start with the anhydrous formula for sodium carbonate: **Na₂CO₃**.

2. Add the number of water molecules using the Greek prefix for “10” (deca): **10H₂O**.

3. Combine them: **Na₂CO₃·10H₂O**.

**Answer**: The formula is **Na₂CO₃·10H₂O**.

### Practice Problem:

Write the chemical formula for calcium chloride dihydrate.

**Answer**: **CaCl₂·2H₂O**

### Section 2: Water in Hydrates—Percent by Mass

Now that we know water is part of a hydrate, we can ask an important question: **How much of a hydrate is actually water?** This is called the **percent by mass of water** in a hydrate, and it’s a useful calculation in chemistry. Here’s how you do it:

1. Find the **molar mass** of the entire hydrate. This includes the anhydrous formula and the attached water molecules.

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

3. Divide the mass of the water by the total mass of the hydrate and multiply by 100 to get the percentage.

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

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

1. **Step 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. **Step 2**: Mass of water = 90.10 g/mol.

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

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

### Practice Problem:

Calculate the percent by mass of water in magnesium sulfate heptahydrate (MgSO₄·7H₂O).

**Answer**: **51.16%**

### Section 3: Reactions Involving Hydrates

Lots of chemical reactions involve hydrates. One common reaction is when a hydrate is heated. This causes the water molecules to be released, leaving behind the **anhydrous compound**.

For example:

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

When heated, copper(II) sulfate pentahydrate loses its water and becomes anhydrous copper(II) sulfate. The blue crystals turn into a white powder!

> ⚡ **Real-World Connection**: This reaction is used in labs to find the formula of an unknown hydrate. By heating it and measuring the lost water, chemists can figure out how many water molecules were attached.

### Solved Sample Problem: Predicting Products of Hydrate Reactions

**Problem**: What happens when calcium chloride dihydrate (**CaCl₂·2H₂O**) is heated?

1. The **anhydrous compound** is **CaCl₂**.

2. The **water molecules** (2H₂O) are released as water vapor.

**Answer**: The reaction is **CaCl₂·2H₂O (s) → CaCl₂ (s) + 2H₂O (g)**.

### Practice Problem:

Predict the products when magnesium sulfate heptahydrate (**MgSO₄·7H₂O**) is heated.

**Answer**: **MgSO₄·7H₂O (s) → MgSO₄ (s) + 7H₂O (g)**

### Section 4: Factors That Affect Percent Yield

Sometimes, reactions involving hydrates don’t go perfectly. The **percent yield** tells us how much product we actually got compared to how much we expected. Here are some factors that can affect percent yield in reactions with hydrates:

1. **Incomplete Reactions**: If not all the hydrate decomposes, you won’t get all the water.

2. **Loss of Product**: Some water vapor might escape before it can be measured.

3. **Impurities**: If your sample isn’t pure, the results could be off.

To calculate percent yield:

**Percent Yield = (Actual Yield / Theoretical Yield) × 100**

### Solved Sample Problem: Percent Yield

**Problem**: You heat a hydrate and collect 1.5 g of water, but you expected 2.0 g. What is the percent yield?

1. Actual Yield = 1.5 g

2. Theoretical Yield = 2.0 g

3. Percent Yield = (1.5 / 2.0) × 100 = **75%**

**Answer**: The percent yield is **75%**.

### Practice Problem:

A reaction produces 5.8 g of a substance, but the theoretical yield is 6.5 g. What is the percent yield?

**Answer**: **89.2%**

### Hands-On Activity: Observing Hydrate Changes

You can try a simple experiment with baking soda! Heat a small spoonful of baking soda (sodium bicarbonate) over a flame. Observe how it changes. What happens to the water inside it? How can you tell?

### Progress Check: Test Your Knowledge

1. **What is a hydrate?**

2. **How do you calculate the percent by mass of water in a hydrate?**

3. **What are some factors that can affect the percent yield of a hydrate reaction?**

**Answers**:

1. A hydrate is a compound with water molecules chemically attached to it.

2. Find the total mass of water in the hydrate, divide it by the total mass of the hydrate, and multiply by 100.

3. Incomplete reactions, loss of product, and impurities can affect percent yield.

### Conclusion

Hydrates are fascinating compounds that show how water can be part of a chemical formula. By understanding their formulas, calculating the percent by mass of water, and predicting reactions, you’ve unlocked an essential tool in chemistry. Next time you see blue crystals or baking soda, think about the hidden water within them—and how chemistry changes them with just a bit of heat!

### 9. Elaborate (Power Up)

Let’s dive deeper into our chemistry lesson with thought-provoking tasks and answers.

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

1. **Why do atoms combine with each other to form molecules?**

- Atoms combine to achieve a stable electronic configuration, usually by completing their outermost energy shell. This is often called the "octet rule."

2. **If a molecule has a strong bond, what does that tell us about its stability and energy?**

- Strong bonds mean the molecule is more stable and less reactive. Breaking such bonds would require significant energy.

3. **Imagine breaking a chemical bond in a molecule. What forms of energy might be involved?**

- Energy required to break bonds is often supplied in the form of heat or light. This energy is called the bond dissociation energy.

4. **How can we predict whether a reaction will produce heat or absorb heat?**

- By determining whether the reaction is exothermic (releases heat) or endothermic (absorbs heat). This can be done by comparing the energy of bonds broken and bonds formed.

**Reinforcement Answer for Each Question:**

The answers provided alongside the questions serve as a guide to help students think critically and connect their learning to real-world phenomena. For example, understanding why atoms bond explains behaviors of various materials, while knowing about bond energy and stability can help predict chemical reactions in everyday life.

### 10. Final Evaluation

**Debate Question:**

**"Should industries prioritize chemical processes that are energy-efficient, even if they are more expensive to develop?"**

**Discussion Points:**

- Energy-efficient processes reduce environmental impact.

- Higher costs today may lead to savings and sustainability in the future.

- Balancing cost and environmental responsibility can be challenging for businesses.

**Short Paragraph for Discussion:**

Industries constantly face the challenge of balancing financial profit with environmental responsibility. While energy-efficient processes often reduce pollution and conserve resources, they can be costly to develop and implement. This raises a question: Should industries prioritize long-term environmental benefits over short-term financial gains?

**Related MCQ:**

What is one long-term benefit of prioritizing energy-efficient chemical processes in industries?

a) Reduced initial development costs

b) Increased environmental pollution

c) Slower adoption of innovative ideas

d) Decreased long-term energy consumption

**Answer:**

**d) Decreased long-term energy consumption**

**Explanation:** Energy-efficient processes typically consume less energy over time, leading to sustainable usage and cost-effectiveness in the long run.

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

1. **What does the octet rule state?**

a) Atoms strive to fill their outer shell with eight protons.

b) Atoms are stable when they share electrons to have eight electrons in their outermost shell.

c) Atoms combine to increase their mass number to eight.

d) Atoms form bonds to become more reactive.

**Answer:** **b**

**Explanation:** The octet rule states that atoms bond to achieve a full outer shell of eight electrons, leading to stability.

2. **Which of the following reactions would likely be endothermic?**

a) Combustion of methane

b) Melting ice into water

c) Condensation of water vapor

d) Freezing water into ice

**Answer:** **b**

**Explanation:** Endothermic reactions absorb heat. Melting ice requires energy input to overcome molecular forces.

3. **A molecule with triple bonds between its atoms would likely be...**

a) Unstable and highly reactive.

b) More stable but have a shorter bond length.

c) Large and flexible due to weak bonding forces.

d) Reactive but with long bond lengths.

**Answer:** **b**

**Explanation:** Triple bonds are strong and hold atoms closer, resulting in higher stability and shorter bond lengths.

4. **Which energy source is most common for breaking chemical bonds in a lab setting?**

a) Sound energy

b) Heat energy

c) Gravitational energy

d) Magnetic energy

**Answer:** **b**

**Explanation:** Heat is the most commonly used energy form in labs for initiating reactions and breaking bonds.

**Long-Answer Questions:**

1. **Explain how the octet rule predicts the way atoms bond. Provide examples.**

**Answer:** The octet rule suggests that atoms bond to complete their outer shells with eight electrons, achieving stability. For instance, in water (H₂O), oxygen shares electrons with two hydrogen atoms to fill its outer shell.

2. **Describe the difference between exothermic and endothermic reactions and give examples of each.**

**Answer:** Exothermic reactions release heat (e.g., combustion of wood), while endothermic reactions absorb heat (e.g., photosynthesis). Exothermic processes feel hot, and endothermic processes feel cold to the touch.

3. **Why are molecules with strong chemical bonds more stable? Relate your answer to bond energy.**

**Answer:** Strong chemical bonds require more energy to break, making the molecule less likely to react under typical conditions. For example, nitrogen gas (N₂) has a strong triple bond, which is why it’s so stable.

4. **Predict what would happen if a chemical reaction breaks more bonds than it forms. Will it absorb or release energy? Why?**

**Answer:** It will absorb energy because breaking bonds requires more energy than is released when new bonds are formed. This is characteristic of an endothermic process.

### 11. Extend (Beyond the Lesson)

**Tasks to Apply Learning to Real-World Scenarios:**

1. **Design a Sustainability Plan:**

Research a real-world chemical industry, such as plastic production or fuel refining, and propose ways they can reduce their energy usage by altering bonding or reaction processes.

2. **Home Experiment:**

Observe endothermic and exothermic reactions at home! Try dissolving salt in water (endothermic) and lighting a candle (exothermic). Write down your observations.

3. **Energy Conversion Challenge:**

Explore how energy is transferred in chemical reactions. For instance, calculate how much energy a reaction like burning fuels releases and compare it to renewable energy sources like solar panels.

**Hints for Upcoming Topics:**

- In the next lesson, we will explore how temperature, pressure, and concentration affect the speed of chemical reactions. Think about how varying these conditions might impact reactions like cooking or rusting!