# Unit: Unit 3: Chemical Reactions and Stoichiometry

## Chapter: Chapter 10: Stoichiometry

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

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### Essential Question:

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

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### 1. Big Idea:

Hydrates are compounds that contain water molecules as part of their structure, and understanding their formulas helps predict how they behave in chemical reactions.

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### 2. Phenomenon-Based Learning:

**Unit Phenomenon:**

How can chemical reactions help improve safety features?

\*Background:\*

Chemical reactions play a key role in safety features like airbags in cars. When airbags deploy, a chemical reaction occurs, releasing gas that inflates the bag. The reaction must be controlled to ensure the products are safe for passengers.

**Chapter Phenomenon:**

Now that we know how to measure matter by mass, volume, and particle count, how do these quantities relate to each other in chemical equations? What is the ratio in which they react?

**Lesson Phenomenon:**

Water is a tricky substance. It can exist on its own or be part of other compounds, like hydrates. Hydrates are compounds that include water molecules in their structure. How do hydrates affect chemical reactions? How should they be counted in a chemical equation?

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### 3. Vocabulary:

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

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

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

- **Hydrate formula:** The chemical formula that shows how many water molecules are bound to the compound (e.g., CuSO₄·5H₂O).

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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):

**Mini-Task:**

Imagine you’re holding a blue crystal of copper(II) sulfate (CuSO₄·5H₂O). What happens if you heat it? Why does it change color?

**Hands-On Task:**

**Materials:**

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

- Bunsen burner or hot plate

- Crucible and tongs

- Balance

- Safety goggles and gloves

**Procedure:**

1. Weigh a small amount of copper(II) sulfate pentahydrate and record its mass.

2. Heat the sample in a crucible over a Bunsen burner or hot plate until it turns white (this indicates the water has been driven off).

3. Let the sample cool and weigh it again.

4. Calculate the mass of water lost by subtracting the final mass from the initial mass.

**Questions:**

1. What happened to the water in the hydrate when it was heated?

2. How would you describe the change in appearance of the compound?

3. How can you calculate the percent by mass of water in the hydrate?

**AI Tool Task:**

Use an online molecular calculator to determine the molar mass of copper(II) sulfate pentahydrate (CuSO₄·5H₂O) and compare it to the anhydrous form (CuSO₄). How much of the molar mass is due to water?

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

**Prior Knowledge:**

Before diving into hydrates, it’s important to recall some key concepts from previous lessons:

- Elements and compounds can combine in fixed ratios.

- Chemical reactions often involve changes in states of matter, like solid to liquid or gas.

- Water is a common product or reactant in many reactions.

**Real-World Connection:**

Have you ever noticed how some products, like silica gel packs, are labeled “Do Not Eat” and are used to keep things dry? These packs contain a substance that absorbs water from the air. In a similar way, hydrates are compounds that have water molecules trapped inside them.

**Background Information:**

Hydrates are compounds that have a specific number of water molecules attached to them. These water molecules are part of the compound’s structure but can be removed by heating. The water in a hydrate is called “water of hydration,” and it can make up a significant portion of the compound’s mass.

For example, copper(II) sulfate pentahydrate (CuSO₄·5H₂O) contains five water molecules for every copper(II) sulfate unit. When heated, the water is released, and the compound becomes anhydrous copper(II) sulfate (CuSO₄), which has a different appearance and properties.

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### 7. Explain (Lightbulb):

**Section 1: What Are Hydrates?**

Hydrates are compounds that contain water molecules as part of their structure. These water molecules are not just mixed with the compound—they are chemically bonded to it. The water in a hydrate is called “water of hydration.”

The formula of a hydrate shows how many water molecules are present. For example, in copper(II) sulfate pentahydrate (CuSO₄·5H₂O), the “5H₂O” means there are five water molecules for every one unit of copper(II) sulfate.

**Sample Problem 1:**

What is the formula of a hydrate that contains two water molecules for every unit of calcium chloride (CaCl₂)?

**Answer:** The formula would be CaCl₂·2H₂O.

**Practice Question:**

Write the formula for a hydrate that contains three water molecules for every unit of sodium carbonate (Na₂CO₃).

**Answer:** Na₂CO₃·3H₂O.

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

One important property of hydrates is the percent by mass of water they contain. This is the percentage of the hydrate’s total mass that comes from water.

To calculate the percent by mass of water in a hydrate, use the following formula:

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

\]

**Sample Problem 2:**

A sample of copper(II) sulfate pentahydrate (CuSO₄·5H₂O) weighs 250 grams. After heating, the remaining anhydrous copper(II) sulfate weighs 160 grams. What is the percent by mass of water in the hydrate?

**Solution:**

1. Mass of water = 250 g (hydrate) - 160 g (anhydrous) = 90 g

2. Percent by mass of water = \(\frac{90}{250} \times 100 = 36\%\)

**Practice Question:**

A sample of magnesium sulfate heptahydrate (MgSO₄·7H₂O) weighs 300 grams. After heating, the remaining anhydrous magnesium sulfate weighs 150 grams. What is the percent by mass of water in the hydrate?

**Answer:** 50%

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**Section 3: Reactions Involving Hydrates**

When hydrates are heated, they lose their water of hydration and become anhydrous. This process is called dehydration. The reverse process, where an anhydrous compound absorbs water to form a hydrate, is called hydration.

**Example:**

When copper(II) sulfate pentahydrate (CuSO₄·5H₂O) is heated, it turns from blue to white as it loses water and becomes anhydrous copper(II) sulfate (CuSO₄).

**Sample Problem 3:**

Predict the products when calcium chloride dihydrate (CaCl₂·2H₂O) is heated.

**Answer:** The products are anhydrous calcium chloride (CaCl₂) and water (H₂O).

**Practice Question:**

What happens when sodium carbonate decahydrate (Na₂CO₃·10H₂O) is heated?

**Answer:** It becomes anhydrous sodium carbonate (Na₂CO₃) and releases water.

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**Section 4: Factors Affecting Percent Yield in Reactions Involving Hydrates**

The percent yield of a reaction is the ratio of the actual yield (what you get) to the theoretical yield (what you expect), expressed as a percentage. In reactions involving hydrates, the percent yield can be affected by:

- Incomplete dehydration (not all the water is removed).

- Loss of material during heating.

- Impurities in the hydrate sample.

**Sample Problem 4:**

If the theoretical yield of anhydrous copper(II) sulfate from a hydrate is 80 grams, but only 75 grams are obtained, what is the percent yield?

**Solution:**

Percent yield = \(\frac{75}{80} \times 100 = 93.75\%\)

**Practice Question:**

If the theoretical yield of anhydrous magnesium sulfate is 100 grams, but only 90 grams are obtained, what is the percent yield?

**Answer:** 90%

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### Conclusion:

Hydrates are compounds that contain water molecules as part of their structure. Understanding their formulas and how they react when heated is important in stoichiometry. By calculating the percent by mass of water in hydrates and predicting the products of reactions involving hydrates, we can better understand the role of water in chemical reactions.

### 8. Evaluate (Progress Check) - Explain

To confirm your understanding of the key concepts, answer the following questions:

1. **What is the difference between a chemical change and a physical change?**

\*Answer\*: A chemical change results in the formation of new substances with different properties, while a physical change only affects the form or appearance of a substance without changing its identity.

2. **What are the signs that a chemical reaction has occurred?**

\*Answer\*: Signs of a chemical reaction include a change in color, the formation of a gas, a change in temperature, the appearance of a precipitate, and sometimes the production of light or sound.

3. **Explain why rusting of iron is considered a chemical change.**

\*Answer\*: Rusting is a chemical change because iron reacts with oxygen in the air to form a new substance, iron oxide (rust), which has different properties from iron.

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### 9. Elaborate (Power Up)

Let's dive deeper into the concepts you've learned. Think about these questions and tasks:

1. **How would you explain the process of photosynthesis as a chemical reaction?**

\*Answer\*: Photosynthesis is a chemical reaction where plants use sunlight to convert carbon dioxide and water into glucose (a sugar) and oxygen. The reaction involves the breaking and forming of chemical bonds, which makes it a chemical change.

2. **Design an experiment to show the difference between a physical and a chemical change.**

\*Answer\*: You could heat water to show a physical change (boiling to steam) and burn a piece of paper to show a chemical change (producing ash and gases).

3. **What might happen if you mixed vinegar and baking soda? What type of change is this?**

\*Answer\*: Mixing vinegar and baking soda produces bubbles of carbon dioxide gas, which is a sign of a chemical reaction. This is a chemical change because new substances (carbon dioxide, water, and sodium acetate) are formed.

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### 10. Final Evaluation

### # Debate Question:

**Should we rely more on chemical reactions to produce energy, such as in batteries and fuel cells, or should we focus on physical processes like solar panels?**

- **Arguments for chemical reactions**: They are efficient and can store energy for later use, like in batteries. Chemical reactions are also used in fuel cells, which are reliable and can be used in many applications, such as cars.

- **Arguments for physical processes**: Solar panels use sunlight (a renewable resource) and don’t produce harmful byproducts. They are also sustainable and can work in many locations.

### # Debate MCQ:

**Which is a key advantage of using chemical reactions for energy production?**

a) They are always renewable.

b) They can store energy for later use.

c) They don’t produce any waste.

d) They rely on sunlight.

\*Correct answer\*: b) They can store energy for later use.

\*Explanation\*: Chemical reactions, like those in batteries, can store energy and release it when needed, unlike solar panels, which rely on sunlight.

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### # ACT Multiple-Choice Questions:

1. **When water freezes, what type of change occurs?**

a) Chemical change

b) Physical change

c) Both chemical and physical change

d) No change occurs

\*Correct answer\*: b) Physical change

\*Explanation\*: Freezing is a physical change because the water changes state from liquid to solid, but its chemical composition remains the same.

2. **Which of the following is an example of a chemical reaction?**

a) Melting ice

b) Dissolving sugar in water

c) Burning wood

d) Breaking glass

\*Correct answer\*: c) Burning wood

\*Explanation\*: Burning wood is a chemical reaction because it produces new substances like ash, carbon dioxide, and water vapor.

3. **Which observation indicates that a chemical change has occurred?**

a) A substance dissolves in water.

b) A gas is produced when two substances are mixed.

c) A solid changes shape when heated.

d) A liquid evaporates.

\*Correct answer\*: b) A gas is produced when two substances are mixed.

\*Explanation\*: The production of gas is a sign that a chemical reaction has occurred, as new substances are being formed.

4. **Why is cooking an egg considered a chemical change?**

a) The egg changes shape.

b) The egg changes color.

c) The proteins in the egg are altered and cannot return to their original state.

d) The egg melts.

\*Correct answer\*: c) The proteins in the egg are altered and cannot return to their original state.

\*Explanation\*: Cooking an egg changes the structure of the proteins, which is a chemical change because it cannot be reversed.

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### # Long-Answer Questions:

1. **Explain why dissolving salt in water is a physical change, but burning wood is a chemical change.**

\*Answer\*: Dissolving salt in water is a physical change because the salt can be recovered by evaporating the water, meaning no new substances are formed. Burning wood, on the other hand, is a chemical change because it produces new substances like ash, carbon dioxide, and water vapor, and the process cannot be reversed.

2. **Describe an experiment that could help you determine whether a change is chemical or physical.**

\*Answer\*: One experiment could be to heat a piece of metal and observe whether it melts (a physical change) or reacts with oxygen to form rust (a chemical change). You could also mix baking soda and vinegar to observe the production of gas, which indicates a chemical reaction.

3. **Why is the rusting of iron considered a slow chemical reaction? What factors can speed up this reaction?**

\*Answer\*: Rusting is a slow chemical reaction because it takes time for iron to react with oxygen and water in the environment. Factors like moisture, salt, and higher temperatures can speed up the rusting process by increasing the rate of the chemical reaction.

4. **How can you tell if a chemical reaction has occurred when two substances are mixed? Provide at least three signs.**

\*Answer\*: You can tell a chemical reaction has occurred if there is a change in color, the formation of a gas (bubbles), the appearance of a precipitate (solid), a change in temperature, or the production of light or sound.

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### 11. Extend (Beyond the Lesson)

To extend your understanding of chemical and physical changes, here are some additional tasks and readings:

1. **Research Task**: Investigate how chemical reactions are used in everyday life, such as in baking, cleaning, or producing energy. Write a short report on one example and explain the chemical changes that occur.

2. **Real-World Application**: Think about how chemical reactions are used in medicine, such as in the development of new drugs. How do scientists use their knowledge of chemical changes to create medicines that can help people?

3. **Challenge Question**: Imagine you are an environmental scientist. How could you use chemical reactions to help clean up pollution in a river?

4. **Spaced Practice**: Over the next few weeks, keep a journal of any chemical or physical changes you observe in your daily life. For example, when you cook food or see something rusting, note down what happens and whether it’s a chemical or physical change.

**Hint for Next Topic**: In the next lesson, we will explore the concept of **energy in chemical reactions**, including how energy is absorbed or released during chemical changes. Get ready to learn about exothermic and endothermic reactions!