# Unit: Unit 3: Chemical Reactions and Stoichiometry

## Chapter: Chapter 10: Stoichiometry

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

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### Essential Questions:

- 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 within their structure, and their composition can be determined by analyzing the percent by mass of water.

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### 2. Essential Questions:

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

**Answer:** Hydrates form when water molecules become part of a compound's crystal structure. The water molecules are not chemically bonded in the same way as other atoms in the compound but are still an integral part of the substance. We can determine the composition of a hydrate by calculating the percent by mass of water in the compound. This can be done by heating the hydrate to remove the water and comparing the mass of the anhydrous compound (without water) to the original hydrate.

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### 3.1 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, 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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### 3.2 Lesson Phenomenon:

Water, when part of a compound's structure, forms hydrates. This water can affect the way the compound behaves in a reaction, and it needs to be considered when calculating the amounts of substances involved.

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### 4. Vocabulary:

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

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

- **Hydrates:** Compounds that contain water molecules within their structure.

- **Hydrate formula:** The chemical formula of a hydrate, which includes the number of water molecules associated with the compound.

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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):

**Phenomenon-Related Question:**

What happens when you heat a hydrate?

**Hands-On Experiment:**

**Materials Needed:**

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

- A Bunsen burner or hot plate

- A crucible and tongs

- A balance (scale)

- Safety goggles

**Procedure:**

1. Weigh a small amount of copper(II) sulfate pentahydrate using the balance. Record the mass.

2. Place the sample in a crucible and heat it gently using the Bunsen burner or hot plate.

3. Observe the color change as the water is driven off. The blue hydrate will turn white or gray as it becomes anhydrous copper(II) sulfate.

4. After heating, allow the crucible to cool and weigh the sample again. Record the new mass.

5. Calculate the mass of water lost during heating by subtracting the final mass from the initial mass.

**Follow-Up Questions:**

1. What color change did you observe during the heating process?

**Answer:** The copper(II) sulfate changed from blue to white or gray as the water was removed.

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

**Answer:** The percent by mass of water can be calculated using the formula:

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

3. Why did the mass of the sample decrease after heating?

**Answer:** The mass decreased because the water molecules were driven off during heating, leaving behind the anhydrous compound.

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

Hydrates are compounds that include water molecules as part of their structure. These water molecules are not chemically bonded in the same way as the atoms in the compound itself but are still essential to the compound's properties. When hydrates are heated, the water is released, and the compound becomes anhydrous (without water). This process is often accompanied by a color change, as seen in the experiment with copper(II) sulfate.

The formula of a hydrate shows how many water molecules are associated with each formula unit of the compound. For example, in copper(II) sulfate pentahydrate (CuSO₄·5H₂O), "pentahydrate" means there are five water molecules for every one copper(II) sulfate unit. The Greek prefix "penta-" means five.

When hydrates are involved in chemical reactions, the water they contain must be accounted for. This is important when calculating the amounts of reactants and products in a reaction, as the water can affect the total mass and the way the compound behaves.

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### 8. Evaluate (Progress Check) - Pre-Explore:

1. What is the difference between a hydrate and an anhydrous compound?

**Answer:** A hydrate contains water molecules as part of its structure, while an anhydrous compound does not.

2. How can you tell if a compound is a hydrate by looking at its formula?

**Answer:** A hydrate's formula will include water molecules, often written as "·xH₂O," where "x" is the number of water molecules.

3. Why is it important to account for the water in a hydrate when calculating the mass of a substance?

**Answer:** The water contributes to the total mass of the hydrate, so it must be included in calculations to ensure accurate results.

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### 9. Explain (Lightbulb):

Hydrates are fascinating because they show how water can be part of a solid structure. In many cases, the water in a hydrate is essential for the compound's stability. For example, copper(II) sulfate is blue when it contains water (CuSO₄·5H₂O), but it turns white or gray when the water is removed, indicating that the water plays a role in the compound's appearance and properties.

### # \*\*Percent by Mass of Water in a Hydrate:\*\*

To calculate the percent by mass of water in a hydrate, follow these steps:

1. **Find the mass of the hydrate.**

This is the mass of the compound before heating, when it still contains water.

2. **Find the mass of the anhydrous compound.**

This is the mass of the compound after heating, when the water has been removed.

3. **Calculate the mass of water lost.**

Subtract the mass of the anhydrous compound from the mass of the hydrate.

4. **Calculate the percent by mass of water.**

Use the formula:

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

**Example Problem:**

A sample of magnesium sulfate heptahydrate (MgSO₄·7H₂O) weighs 15.0 g. After heating, the mass of the anhydrous magnesium sulfate is 7.4 g. What is the percent by mass of water in the hydrate?

**Solution:**

1. Mass of hydrate = 15.0 g

2. Mass of anhydrous compound = 7.4 g

3. Mass of water lost = 15.0 g - 7.4 g = 7.6 g

4. Percent by mass of water = \( \left( \frac{7.6}{15.0} \right) \times 100 = 50.67\% \)

**Progress Check:**

A sample of barium chloride dihydrate (BaCl₂·2H₂O) weighs 20.0 g. After heating, the mass of the anhydrous compound is 16.0 g. What is the percent by mass of water in the hydrate?

**Answer:**

Mass of water lost = 20.0 g - 16.0 g = 4.0 g

Percent by mass of water = \( \left( \frac{4.0}{20.0} \right) \times 100 = 20\% \)

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### # \*\*Predicting Reactions Involving Hydrates:\*\*

When hydrates are heated, they lose water and become anhydrous. This is a physical change, not a chemical reaction. However, in some cases, the anhydrous compound may undergo further chemical reactions once the water is removed.

For example, if you heat sodium carbonate decahydrate (Na₂CO₃·10H₂O), it will lose its water and become anhydrous sodium carbonate (Na₂CO₃). If you continue heating the anhydrous sodium carbonate, it may decompose into sodium oxide (Na₂O) and carbon dioxide (CO₂).

**Example Problem:**

What products would you expect if you heat copper(II) sulfate pentahydrate (CuSO₄·5H₂O)?

**Solution:**

When heated, copper(II) sulfate pentahydrate will lose its water and become anhydrous copper(II) sulfate (CuSO₄). The water will be released as water vapor (H₂O).

**Progress Check:**

What products would you expect if you heat calcium chloride dihydrate (CaCl₂·2H₂O)?

**Answer:**

When heated, calcium chloride dihydrate will lose its water and become anhydrous calcium chloride (CaCl₂). The water will be released as water vapor (H₂O).

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### # \*\*Factors Affecting Percent Yield:\*\*

In many chemical reactions, the actual yield (the amount of product obtained) is less than the theoretical yield (the amount of product expected based on stoichiometric calculations). This difference is often due to factors such as:

1. **Incomplete reactions:** Not all of the reactants may be converted into products.

2. **Side reactions:** Other reactions may occur, producing unwanted products.

3. **Loss of product during handling:** Some product may be lost during transfer, filtration, or other steps.

When hydrates are involved, the percent yield can also be affected by how much water is lost during heating. If the hydrate is not heated long enough, some water may remain, leading to a higher mass than expected for the anhydrous compound.

**Example Problem:**

A chemist heats 10.0 g of copper(II) sulfate pentahydrate (CuSO₄·5H₂O) and expects to obtain 6.4 g of anhydrous copper(II) sulfate (CuSO₄). However, after heating, the mass of the anhydrous compound is only 6.0 g. What is the percent yield?

**Solution:**

Theoretical yield = 6.4 g

Actual yield = 6.0 g

Percent yield = \( \left( \frac{6.0}{6.4} \right) \times 100 = 93.75\% \)

**Progress Check:**

A chemist heats 5.0 g of barium chloride dihydrate (BaCl₂·2H₂O) and expects to obtain 4.2 g of anhydrous barium chloride (BaCl₂). However, after heating, the mass of the anhydrous compound is 4.0 g. What is the percent yield?

**Answer:**

Theoretical yield = 4.2 g

Actual yield = 4.0 g

Percent yield = \( \left( \frac{4.0}{4.2} \right) \times 100 = 95.24\% \)

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### Conclusion:

Hydrates are an important class of compounds that contain water molecules as part of their structure. By heating a hydrate, we can remove the water and determine the percent by mass of water in the compound. This information is useful in many chemical reactions, especially when calculating the amounts of reactants and products. Additionally, understanding how hydrates behave in reactions can help us predict the outcome of chemical processes and analyze factors that affect the percent yield of a reaction.

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

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

- **Answer**: A physical change is when a substance changes its form (like ice melting into water) but remains the same substance. A chemical change, on the other hand, creates a new substance (like burning wood turning into ash and smoke).

2. **Why does the mass of a substance stay the same during a physical change?**

- **Answer**: The mass stays the same because no new substance is formed. Only the shape or state of the substance changes, but the amount of matter remains constant.

3. **How can you tell if a chemical reaction has occurred?**

- **Answer**: You can tell if a chemical reaction has occurred by looking for signs like a change in color, the formation of a gas, a change in temperature, or the formation of a solid (precipitate) from a liquid.

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### 11. Elaborate (Power Up)

1. **Mini-task: Create a real-life example of both a physical and chemical change. Explain what is happening in each case.**

- **Answer**: A real-life example of a physical change is ice melting into water. The ice changes from solid to liquid, but it is still H₂O. A chemical change example is baking a cake. The ingredients (flour, eggs, sugar) react with heat, forming a new substance that cannot be reversed into its original ingredients.

2. **Open-ended question: Why is it important to understand the difference between physical and chemical changes in everyday life?**

- **Answer**: Understanding the difference helps us in many ways. For example, knowing that cooking involves chemical changes helps us understand why food can't "uncook." Similarly, knowing that water freezing is a physical change helps us realize that the process can be reversed by melting the ice.

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### 12. Final Evaluation

### # Debate Question:

- **Should we be more concerned about chemical changes in the environment than physical changes?**

- **Arguments for discussion**:

- Chemical changes can create harmful substances (like pollution or toxic waste) that are difficult to reverse.

- Physical changes, like erosion, can also cause damage but might not create new harmful substances.

- Chemical changes can affect the air, water, and soil, leading to long-term environmental issues.

- Physical changes, such as melting glaciers, are also a concern, but they may not result in new dangerous compounds.

### # Multiple-Choice Questions:

1. **Which of the following is a physical change?**

- a) Rusting of iron

- b) Burning of wood

- c) Melting of ice

- d) Cooking an egg

- **Correct Answer**: c) Melting of ice

**Explanation**: Melting is a physical change because the substance (water) remains the same, only changing its state from solid to liquid.

2. **What is a sign that a chemical change has occurred?**

- a) A change in shape

- b) A change in color

- c) A change in size

- d) A change in texture

- **Correct Answer**: b) A change in color

**Explanation**: A color change often indicates a chemical reaction, such as when iron rusts and turns reddish-brown.

3. **Which of the following is a chemical change?**

- a) Boiling water

- b) Dissolving sugar in water

- c) Burning paper

- d) Cutting paper

- **Correct Answer**: c) Burning paper

**Explanation**: Burning paper results in ash and smoke, which are new substances, indicating a chemical change.

4. **Why does the mass of a substance remain the same during a physical change?**

- a) Because the substance changes into a new one

- b) Because no new substance is created

- c) Because energy is absorbed

- d) Because the substance disappears

- **Correct Answer**: b) Because no new substance is created

**Explanation**: During a physical change, the substance retains its identity, so the mass remains unchanged.

### # Long-Answer Questions:

1. **Explain how you would distinguish between a chemical and a physical change using examples.**

- **Answer**: To distinguish between a chemical and physical change, I would look for the formation of new substances. For example, tearing paper is a physical change because the paper is still paper, just in smaller pieces. In contrast, burning paper is a chemical change because it turns into ash and smoke, which are new substances.

2. **Describe a situation where a physical change is useful in everyday life.**

- **Answer**: A physical change is useful when we freeze water to make ice. We can use ice to keep drinks cold, and when it melts, it turns back into water, which is still useful. The ability to reverse the change makes it practical for cooling purposes.

3. **Why is it important to recognize chemical changes in cooking?**

- **Answer**: Recognizing chemical changes in cooking is important because once food undergoes a chemical change, it cannot return to its original state. For example, when you bake bread, the dough rises and forms a new structure due to chemical reactions. Understanding these changes helps us control the cooking process and achieve the desired results.

4. **How does the conservation of mass apply to chemical reactions?**

- **Answer**: The conservation of mass states that mass cannot be created or destroyed in a chemical reaction. This means that the total mass of the reactants equals the total mass of the products. For example, when hydrogen gas reacts with oxygen to form water, the mass of the water produced is equal to the combined mass of the hydrogen and oxygen.

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### 13. Extend (Beyond the Lesson)

1. **Additional Task: Research how chemical changes are involved in recycling processes.**

- **Challenge**: Investigate how plastic is chemically broken down during recycling and how it is reformed into new products. Write a short report on the benefits and challenges of these chemical changes in recycling.

2. **Real-World Application: How does understanding physical and chemical changes help in environmental conservation?**

- **Answer**: Understanding these changes helps in environmental conservation by allowing us to predict and control the effects of human activities. For example, knowing that burning fossil fuels (a chemical change) releases harmful gases helps us find cleaner energy alternatives. Similarly, understanding physical changes like soil erosion helps in developing ways to prevent land degradation.

3. **Spaced Practice Activity:**

- **Task**: Over the next week, observe and record at least five examples of physical and chemical changes in your daily life. For each example, explain why it is a physical or chemical change. This will help reinforce your understanding of the concepts over time.

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This lesson structure ensures that students not only understand the basic concepts of physical and chemical changes but also apply their knowledge to real-world situations, encouraging deeper thinking and long-term retention.