# Unit 3: Chemical Reactions and Stoichiometry

## Chapter 10: Stoichiometry

# Lesson 4: Hydrates: Their Formulas and Reactions

### 1. Big Idea:

Hydrates are compounds that include water molecules as part of their structure, and understanding their formulas helps predict how they react in chemical processes.

### 2. Phenomenon-Based Learning:

- **Unit Phenomenon:**

How can chemical reactions help improve safety features?

- **Chapter Phenomenon:**

How do quantities of matter relate to each other in a chemical equation?

- **Lesson Phenomenon:**

Water is often part of chemical reactions, sometimes as a standalone substance and other times as part of a compound called a hydrate. How do hydrates affect chemical reactions, and how should they be counted?

### 3. Vocabulary:

- **Anhydrous formula:**

The chemical formula of a compound without water molecules attached.

- **Greek prefix:**

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

- **Hydrates:**

Compounds that contain water molecules within their structure.

- **Hydrate formula:**

The chemical formula of a hydrate, showing the number of water molecules attached to the compound (e.g., CuSO₄·5H₂O).

### 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.

### 5. Engage (Ignite):

**Pathfinder: Phenomenon-related question:**

How does water affect the behavior of certain compounds during chemical reactions?

**Mini Task:**

Create a simple experiment to observe how hydrates lose water when heated.

**Materials Needed:**

- Epsom salt (MgSO₄·7H₂O)

- Heat source (Bunsen burner or hot plate)

- Weighing scale

- Tongs

- Heat-resistant container

**Procedure:**

1. Weigh a small amount of Epsom salt and record its mass.

2. Heat the salt gently using a Bunsen burner or hot plate.

3. Observe any changes (e.g., water vapor being released, color change).

4. After heating, reweigh the salt and compare the mass before and after heating.

**Questions:**

1. What happened to the mass of the salt after heating?

- **Answer:** The mass decreased because the water molecules were released.

2. What does this tell you about the role of water in hydrates?

- **Answer:** Water is part of the structure of hydrates and can be removed by heating.

3. How might this change affect the chemical reactions involving hydrates?

- **Answer:** Removing water could change how the hydrate reacts in further chemical processes.

**AI Tool Task:**

Use an AI-based chemistry simulator to predict how different hydrates behave when heated. Ask the AI: "What happens to the mass of a hydrate as it loses water?"

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

**Background Knowledge:**

In earlier lessons, the concept of chemical reactions and how substances combine has been explored. You’ve also learned how to balance chemical equations and calculate molar masses. Now, it’s time to dive into hydrates—compounds that include water as part of their structure.

**Real-World Example:**

Think about Epsom salt (MgSO₄·7H₂O), which is often used in baths to soothe muscles. Epsom salt is a hydrate, meaning it contains water molecules within its structure. When you heat it, the water molecules are released, and the salt changes its form. This is similar to how hydrates behave in chemical reactions.

**Linking the Phenomenon:**

Water is essential in many chemical reactions. Sometimes, it’s part of the reaction itself, and other times, it’s bound within a compound like a hydrate. Understanding how hydrates work can help us predict how they will behave in reactions, such as those that occur in airbags or other safety features in cars.

### 7. Explain (Lightbulb):

### Section 1: What Are Hydrates?

Hydrates are compounds that have water molecules attached to them in a specific ratio. The water molecules are part of the compound’s structure, but they can be removed by heating. When the water is removed, the compound is said to be **anhydrous**.

**Example:**

Copper(II) sulfate pentahydrate (CuSO₄·5H₂O) is a hydrate. The "·5H₂O" means that for every one molecule of CuSO₄, there are five water molecules attached. If you heat CuSO₄·5H₂O, it loses the water and becomes anhydrous CuSO₄.

**Sample Problem 1: Writing the Formula of a Hydrate**

A compound of magnesium sulfate contains seven water molecules for every one magnesium sulfate molecule. Write the formula for this hydrate.

**Solution:**

The formula is MgSO₄·7H₂O.

**Practice Question:**

Write the formula for a hydrate that contains two water molecules for every one molecule of calcium chloride.

- **Answer:** CaCl₂·2H₂O

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

The percent by mass of water in a hydrate is the percentage of the compound’s total mass that comes from the water molecules. To calculate this, you need to know the molar mass of the hydrate and the molar mass of the water molecules.

**Formula:**

\[

\text{Percent by mass of water} = \frac{\text{Mass of water in the hydrate}}{\text{Total mass of the hydrate}} \times 100

\]

**Example:**

Let’s calculate the percent by mass of water in CuSO₄·5H₂O.

1. Find the molar mass of CuSO₄:

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

2. Find the molar mass of 5H₂O:

H₂O = 2 × 1.01 + 16.00 = 18.02 g/mol

5H₂O = 5 × 18.02 = 90.10 g/mol

3. Total molar mass of CuSO₄·5H₂O = 159.62 + 90.10 = 249.72 g/mol

4. Percent by mass of water:

\[

\frac{90.10}{249.72} \times 100 = 36.08\%

\]

**Practice Question:**

Calculate the percent by mass of water in MgSO₄·7H₂O.

- **Answer:** 51.2%

### Section 3: Reactions Involving Hydrates

When hydrates are heated, they lose their water molecules and become anhydrous. This process is called **dehydration**. The anhydrous compound can then participate in other chemical reactions.

**Example:**

When you heat CuSO₄·5H₂O, it loses water and becomes anhydrous CuSO₄. The reaction can be written as:

\[

\text{CuSO₄·5H₂O} \xrightarrow{\text{heat}} \text{CuSO₄} + 5\text{H₂O}

\]

**Sample Problem 2: Predicting the Products of a Hydrate Reaction**

What are the products when MgSO₄·7H₂O is heated?

**Solution:**

The products are anhydrous MgSO₄ and 7H₂O.

**Practice Question:**

What are the products when CaCl₂·2H₂O is heated?

- **Answer:** Anhydrous CaCl₂ and 2H₂O

### Section 4: Factors Affecting Percent Yield in Hydrate Reactions

The **percent yield** of a reaction is the percentage of the expected product that is actually produced. In reactions involving hydrates, the percent yield can be affected by several factors, such as incomplete dehydration or loss of product during heating.

**Example:**

If 10 grams of CuSO₄·5H₂O is heated, and only 7 grams of anhydrous CuSO₄ is obtained, the percent yield can be calculated as:

\[

\text{Percent yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100

\]

If the theoretical yield is 8 grams, then:

\[

\text{Percent yield} = \frac{7}{8} \times 100 = 87.5\%

\]

**Practice Question:**

If 12 grams of MgSO₄·7H₂O is heated and 6 grams of anhydrous MgSO₄ is obtained, what is the percent yield?

- **Answer:** 75%

### 8. Conclusion

Hydrates are unique compounds that contain water molecules within their structure. Understanding their formulas and how they react when heated is important for predicting chemical reactions. By calculating the percent by mass of water and predicting the products of hydrate reactions, we can better understand how these compounds behave in real-world applications, such as airbags in cars, where chemical reactions must be carefully controlled to ensure safety.

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

Let's check your understanding of the key concepts we’ve covered so far. Answer these questions to see how well you understand the material.

**Question 1:**

What is the chemical formula for water?

**Answer:**

The chemical formula for water is H₂O. This means each molecule of water contains two hydrogen atoms and one oxygen atom.

**Question 2:**

Why do atoms bond together to form molecules?

**Answer:**

Atoms bond together to achieve a more stable electron configuration. Most atoms bond to fill their outer electron shells, which makes them more stable.

**Question 3:**

Explain how ionic bonds and covalent bonds are different.

**Answer:**

Ionic bonds form when one atom transfers electrons to another, resulting in positive and negative ions that attract each other. Covalent bonds form when two atoms share electrons to fill their outer shells.

### 9. Elaborate (Power Up)

Now, let's dive a little deeper. These tasks will help you think more critically about what you've learned.

**Mini-task 1:**

List three examples of compounds that are formed through ionic bonding. Explain why they are ionic.

**Answer:**

1. **Sodium chloride (NaCl)** – Sodium donates an electron to chlorine, forming Na⁺ and Cl⁻ ions.

2. **Magnesium oxide (MgO)** – Magnesium gives up two electrons to oxygen, forming Mg²⁺ and O²⁻ ions.

3. **Calcium fluoride (CaF₂)** – Calcium gives two electrons to two fluorine atoms, forming Ca²⁺ and F⁻ ions.

**Mini-task 2:**

Describe a real-world example where understanding chemical bonding is important.

**Answer:**

Understanding chemical bonding is important in medicine. For example, the way drugs interact with cells often depends on the type of bonds they form. Some drugs form covalent bonds with enzymes, blocking their activity, which can help treat diseases.

**Mini-task 3:**

How might the properties of a substance change if it were made of covalent bonds instead of ionic bonds?

**Answer:**

Substances with covalent bonds tend to have lower melting and boiling points compared to ionic compounds. They are also usually poor conductors of electricity because they do not have free ions.

### 10. Final Evaluation

**Debate Question:**

Should governments invest more in developing alternative energy sources like solar and wind power, given the chemical processes involved in burning fossil fuels?

**Arguments for discussion:**

- Burning fossil fuels releases carbon dioxide, contributing to climate change.

- Solar and wind energy do not produce harmful emissions.

- However, alternative energy sources can be expensive to develop and maintain.

**MCQ Question:**

Which of the following is a benefit of using solar energy over fossil fuels?

A) It produces more energy per unit.

B) It is cheaper to produce.

C) It does not release carbon dioxide.

D) It is available at all times.

**Correct Answer:** C) It does not release carbon dioxide.

**Explanation:** Solar energy is a clean energy source because it does not emit carbon dioxide, unlike fossil fuels.

### ACT Multiple-Choice Questions

**Paragraph:**

When sodium (Na) reacts with chlorine (Cl), sodium donates one electron to chlorine. This creates a positive sodium ion (Na⁺) and a negative chloride ion (Cl⁻). These ions are held together by an ionic bond, forming sodium chloride (NaCl), also known as table salt.

**Question 1:**

What type of bond is formed between sodium and chlorine?

A) Covalent bond

B) Hydrogen bond

C) Ionic bond

D) Metallic bond

**Correct Answer:** C) Ionic bond

**Explanation:** Sodium and chlorine form an ionic bond because sodium donates an electron to chlorine, creating ions.

**Paragraph:**

Water (H₂O) is a covalent compound where the oxygen atom shares electrons with two hydrogen atoms. This sharing of electrons allows each atom to fill its outer electron shell, making the molecule stable.

**Question 2:**

What type of bond holds the atoms in a water molecule together?

A) Ionic bond

B) Covalent bond

C) Metallic bond

D) Hydrogen bond

**Correct Answer:** B) Covalent bond

**Explanation:** In water, the oxygen and hydrogen atoms share electrons, which is characteristic of a covalent bond.

**Paragraph:**

Magnesium oxide (MgO) is formed when magnesium (Mg) reacts with oxygen (O). Magnesium loses two electrons to become Mg²⁺, and oxygen gains two electrons to become O²⁻. These oppositely charged ions attract each other, forming an ionic bond.

**Question 3:**

Why do magnesium and oxygen form an ionic bond?

A) Magnesium shares electrons with oxygen.

B) Magnesium and oxygen both gain electrons.

C) Magnesium loses electrons, and oxygen gains electrons.

D) Magnesium and oxygen share protons.

**Correct Answer:** C) Magnesium loses electrons, and oxygen gains electrons.

**Explanation:** Ionic bonds form when one atom loses electrons and another gains them, as seen with magnesium and oxygen.

**Paragraph:**

Covalent compounds like methane (CH₄) have different properties compared to ionic compounds like sodium chloride (NaCl). Covalent compounds typically have lower melting points and do not conduct electricity, while ionic compounds have higher melting points and conduct electricity when dissolved in water.

**Question 4:**

Which of the following is a property of covalent compounds?

A) High melting points

B) Conduct electricity in water

C) Low melting points

D) Form ions in solution

**Correct Answer:** C) Low melting points

**Explanation:** Covalent compounds generally have lower melting points compared to ionic compounds.

### Long-Answer Questions

**Question 1:**

Describe the difference between a covalent bond and an ionic bond, and provide an example of each.

**Answer:**

A covalent bond is formed when two atoms share electrons, such as in a water molecule (H₂O). An ionic bond occurs when one atom donates electrons to another, creating oppositely charged ions that attract each other, like in sodium chloride (NaCl).

**Question 2:**

Explain why ionic compounds tend to have higher melting points than covalent compounds.

**Answer:**

Ionic compounds have higher melting points because the electrostatic forces between the positive and negative ions are very strong. It takes more energy to break these bonds compared to the weaker forces holding covalent molecules together.

**Question 3:**

How does the type of chemical bond affect the electrical conductivity of a substance?

**Answer:**

Ionic compounds conduct electricity when dissolved in water because the ions are free to move. Covalent compounds, on the other hand, do not conduct electricity because they do not form ions in solution.

**Question 4:**

Why is it important to understand chemical bonding when developing new materials?

**Answer:**

Understanding chemical bonding helps scientists design materials with specific properties, such as strength, flexibility, or conductivity. For example, knowing how atoms bond can help create stronger alloys or more efficient solar panels.

### 11. Extend (Beyond the Lesson)

To deepen your understanding, try these additional tasks and readings:

**Task 1:**

Research how chemical bonding is used in the development of new medicines. Write a short paragraph explaining how understanding covalent and ionic bonds helps in drug design.

**Task 2:**

Explore the role of chemical bonding in environmental science. How do the bonds in carbon dioxide (CO₂) contribute to global warming? Write a brief explanation.

**Task 3:**

Read about the next topic: **"Intermolecular Forces"**. These forces are weaker than ionic or covalent bonds but still play a crucial role in determining the properties of substances. How do intermolecular forces affect the boiling point of water?

**Spaced Practice:**

Over the next few weeks, revisit these questions and concepts. Try to explain them in your own words or teach them to a friend. This will help reinforce your understanding over time.