# Unit: Unit 3: Chemical Reactions and Stoichiometry

## Chapter: Chapter 10: Stoichiometry

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

# Lesson Plan: 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 understanding their formulas helps predict how they behave in chemical reactions.

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### 2. Phenomenon-Based Learning:

**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?

**Unit Phenomenon**:

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. Airbags deploy rapidly during a crash, filling with gas from a chemical reaction. The products of the reaction must be safe for passengers, and water can sometimes play a role in these reactions. Hydrates, which contain water, might affect how these reactions happen.

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### 3. Vocabulary:

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

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

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

- **Hydrate formula**: The chemical formula of a hydrate, showing the number of water molecules per formula unit of the compound.

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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 are designing a new car airbag. The chemical reaction inside the airbag must be fast and safe. What happens if the chemical used contains water as part of its structure? How would this affect the reaction?

**Hands-On Task**:

**Materials**:

- Epsom salt (MgSO₄·7H₂O),

- A heat source (like a Bunsen burner or hot plate),

- A balance,

- A crucible or small metal container.

**Procedure**:

1. Weigh about 5 grams of Epsom salt (a hydrate) and record the mass.

2. Gently heat the Epsom salt in the crucible until it turns white and stops releasing water vapor.

3. After cooling, weigh the remaining white powder (the anhydrous form of Epsom salt).

4. Calculate the mass of water lost during heating.

**Questions**:

1. What was the original mass of the hydrate?

2. What is the mass of the anhydrous compound after heating?

3. How much water was lost, and what percentage of the original mass was water?

**Answers**:

1. Approximately 5 grams (depending on the exact amount used).

2. The mass of the anhydrous compound will be less than the hydrate.

3. The difference in mass is the water lost. The percentage of water can be calculated as (mass of water lost / original mass) × 100.

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

Hydrates are compounds that have water molecules incorporated into their structure. These water molecules are not just loosely attached; they are part of the solid's crystalline structure. For example, Epsom salt (MgSO₄·7H₂O) contains seven water molecules for every magnesium sulfate unit. This is why it feels damp even though it looks like a solid.

In everyday life, hydrates are common. For instance, the silica gel packets found in new shoes or electronics are used to absorb moisture. These packets contain an anhydrous form of silica that can trap water and become a hydrate.

When a hydrate is heated, the water molecules are released as vapor, and the compound becomes "anhydrous," meaning it no longer contains water. This process is reversible for some hydrates, which can absorb water from the air and return to their hydrated form.

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

1. What is a hydrate?

**Answer**: A compound that contains water molecules as part of its structure.

2. What happens when a hydrate is heated?

**Answer**: The water molecules are released, and the compound becomes anhydrous.

3. Why do silica gel packets absorb moisture?

**Answer**: They contain an anhydrous substance that can trap water, turning into a hydrate.

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### 8. Explain (Lightbulb):

### # Introduction to Hydrates:

Hydrates are compounds that include water molecules within their crystalline structure. The water in a hydrate is not just mixed in; it's chemically bonded to the compound. For example, copper(II) sulfate pentahydrate (CuSO₄·5H₂O) contains five water molecules for each copper(II) sulfate unit. These water molecules are essential to the structure of the hydrate.

### # Hydrate Formulas:

The formula of a hydrate is written as the compound followed by a dot and the number of water molecules. For example, magnesium sulfate heptahydrate (Epsom salt) is written as MgSO₄·7H₂O. The "7H₂O" means there are seven water molecules for every formula unit of magnesium sulfate.

The number of water molecules in a hydrate is indicated by a Greek prefix:

- Mono- (1 water molecule)

- Di- (2 water molecules)

- Tri- (3 water molecules)

- Tetra- (4 water molecules)

- Penta- (5 water molecules)

- Hexa- (6 water molecules)

- Hepta- (7 water molecules)

### # Anhydrous Compounds:

When a hydrate is heated, the water molecules are released as steam, leaving behind the anhydrous form of the compound. For instance, when copper(II) sulfate pentahydrate is heated, it turns from blue to white as the water evaporates, leaving behind anhydrous copper(II) sulfate (CuSO₄).

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

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

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

\]

For example, in magnesium sulfate heptahydrate (MgSO₄·7H₂O), the molar mass of MgSO₄ is 120.37 g/mol, and the molar mass of 7H₂O is 7 × 18.02 = 126.14 g/mol. The total molar mass of MgSO₄·7H₂O is 120.37 + 126.14 = 246.51 g/mol. The percent by mass of water is:

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\left( \frac{126.14}{246.51} \right) \times 100 = 51.2\%

\]

### # Predicting Reactions Involving Hydrates:

When hydrates are involved in chemical reactions, the water molecules must be accounted for. For example, if copper(II) sulfate pentahydrate (CuSO₄·5H₂O) reacts with sulfuric acid, the reaction will involve both the CuSO₄ and the water molecules. The products of the reaction will depend on whether the hydrate is heated or not.

### # Factors Affecting Percent Yield:

In reactions involving hydrates, the percent yield can be affected by factors like incomplete dehydration (not all the water is removed) or contamination from moisture in the air. If a hydrate is not fully heated, some water may remain, leading to a lower-than-expected yield of the anhydrous compound.

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### # Solved Sample Problem 1:

**Problem**: A 10.0 g sample of a hydrate of barium chloride (BaCl₂·xH₂O) is heated until all the water is driven off. The mass of the anhydrous barium chloride (BaCl₂) left behind is 8.53 g. What is the value of x (the number of water molecules per formula unit)?

**Solution**:

1. The mass of water lost is 10.0 g - 8.53 g = 1.47 g.

2. The molar mass of BaCl₂ is 208.23 g/mol, and the molar mass of H₂O is 18.02 g/mol.

3. Moles of BaCl₂ = 8.53 g ÷ 208.23 g/mol = 0.04097 mol.

4. Moles of H₂O = 1.47 g ÷ 18.02 g/mol = 0.08157 mol.

5. The ratio of moles of H₂O to BaCl₂ is 0.08157 ÷ 0.04097 = 1.99 ≈ 2.

So, the formula of the hydrate is BaCl₂·2H₂O.

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### # Practice Question:

A 15.0 g sample of a hydrate of calcium sulfate (CaSO₄·xH₂O) is heated until all the water is removed. The mass of the anhydrous calcium sulfate (CaSO₄) is 12.0 g. What is the value of x?

**Answer**:

1. Mass of water lost = 15.0 g - 12.0 g = 3.0 g.

2. Molar mass of CaSO₄ = 136.14 g/mol, molar mass of H₂O = 18.02 g/mol.

3. Moles of CaSO₄ = 12.0 g ÷ 136.14 g/mol = 0.0881 mol.

4. Moles of H₂O = 3.0 g ÷ 18.02 g/mol = 0.1665 mol.

5. Ratio of moles of H₂O to CaSO₄ = 0.1665 ÷ 0.0881 = 1.89 ≈ 2.

The formula of the hydrate is CaSO₄·2H₂O.

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### Summary:

Hydrates are compounds that contain water molecules within their structure. By understanding their formulas and how they react, we can predict the outcomes of chemical reactions involving hydrates. Calculating the percent by mass of water in a hydrate and predicting the products of reactions are essential skills in stoichiometry.

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

To confirm your understanding of the key concepts covered in the "Explain" section, here are three scaffolded questions. Try to answer them to check your grasp of the material!

1. **What is the chemical formula for water?**

- **Answer**: The chemical formula for water is **H₂O**. This means each water molecule consists of two hydrogen atoms and one oxygen atom.

2. **Why do atoms form chemical bonds?**

- **Answer**: Atoms form chemical bonds to achieve a full outer shell of electrons, which makes them more stable. For example, in a water molecule, oxygen shares electrons with hydrogen atoms to fill its outer shell.

3. **Explain how ionic bonds and covalent bonds are different.**

- **Answer**: In an **ionic bond**, electrons are transferred from one atom to another, creating charged ions that attract each other. In a **covalent bond**, atoms share electrons to fill their outer shells. For example, sodium and chlorine form an ionic bond in table salt, while hydrogen and oxygen share electrons in a covalent bond to form water.

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### 11. Elaborate (Power Up)

Now, let's dive deeper into the concepts. These mini-tasks will encourage you to think more critically about what you've learned.

1. **Mini-Task**: Draw a diagram of a water molecule and label the bonds. Explain why the molecule has a bent shape.

- **Answer**: A water molecule has a bent shape because of the two lone pairs of electrons on the oxygen atom. These lone pairs repel the hydrogen atoms, pushing them closer together and creating a bond angle of about 104.5 degrees. The bonds between oxygen and hydrogen are covalent, meaning the atoms share electrons.

2. **Open-Ended Question**: How would the properties of water change if it were held together by ionic bonds instead of covalent bonds?

- **Answer**: If water were held together by ionic bonds, it would likely be a solid at room temperature, as ionic compounds typically have higher melting and boiling points than covalent compounds. The unique properties of water, such as its ability to dissolve many substances and its liquid state at room temperature, are due to its covalent bonds and hydrogen bonding.

3. **Mini-Task**: Research and write a short paragraph about how water's polarity makes it an excellent solvent.

- **Answer**: Water is a polar molecule, meaning one side (the oxygen side) is slightly negative, and the other side (the hydrogen side) is slightly positive. This polarity allows water to dissolve many substances, especially ionic compounds and polar molecules. The positive and negative ends of water molecules surround and separate the ions or molecules of the substance, effectively dissolving it.

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### 12. Final Evaluation

**Debate Question**:

**Should we continue using water as a universal solvent in industrial processes, even though it can lead to pollution?**

- **Arguments for**: Water is abundant, cheap, and highly effective at dissolving many substances, making it ideal for industrial use. Its properties make it difficult to replace with other solvents.

- **Arguments against**: Using water in industrial processes often leads to pollution, including contamination of drinking water sources. Alternatives like green solvents could reduce environmental harm.

**MCQ**:

What is the main reason water is considered a "universal solvent"?

A) It has a high boiling point.

B) It can dissolve both ionic and polar substances.

C) It is a covalent compound.

D) It is abundant on Earth.

- **Correct Answer**: B) It can dissolve both ionic and polar substances.

- **Explanation**: Water's polarity allows it to dissolve a wide range of substances, making it a versatile solvent.

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### # ACT-Style Multiple-Choice Questions

**Question 1**:

Water has a high surface tension because:

A) It forms ionic bonds.

B) It has a bent molecular shape.

C) It forms hydrogen bonds between molecules.

D) It is a polar molecule.

- **Correct Answer**: C) It forms hydrogen bonds between molecules.

- **Explanation**: The hydrogen bonds between water molecules create a "sticky" surface, leading to high surface tension.

**Question 2**:

Which of the following best describes an ionic bond?

A) Electrons are shared equally between atoms.

B) Electrons are transferred from one atom to another.

C) Atoms are held together by hydrogen bonds.

D) Electrons are shared unequally between atoms.

- **Correct Answer**: B) Electrons are transferred from one atom to another.

- **Explanation**: In an ionic bond, one atom loses electrons and becomes positively charged, while the other gains electrons and becomes negatively charged.

**Question 3**:

Which property of water allows it to travel up plant stems against gravity?

A) High surface tension

B) Capillary action

C) High boiling point

D) Cohesion

- **Correct Answer**: B) Capillary action

- **Explanation**: Capillary action is the ability of water to flow in narrow spaces without the assistance of external forces, which helps water move up plant stems.

**Question 4**:

Why is ice less dense than liquid water?

A) Water molecules are closer together in ice.

B) Water molecules form a crystalline structure in ice.

C) Ice has fewer hydrogen bonds than liquid water.

D) Ice is made of covalent bonds, while water is ionic.

- **Correct Answer**: B) Water molecules form a crystalline structure in ice.

- **Explanation**: In ice, water molecules form a hexagonal crystalline structure, which takes up more space than the liquid form, making ice less dense.

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### # Long-Answer Questions

**Question 1**:

Explain how water's polarity contributes to its role as a solvent in biological systems.

- **Answer**: Water's polarity allows it to dissolve many substances essential for life, such as salts, sugars, and gases. The positive and negative ends of water molecules surround and separate ions or polar molecules, making them available for biological processes like metabolism and transport within cells.

**Question 2**:

Describe the process of hydrogen bonding in water and its effects on water's properties.

- **Answer**: Hydrogen bonding occurs when the slightly positive hydrogen atoms of one water molecule are attracted to the slightly negative oxygen atoms of another water molecule. This bonding gives water its high boiling point, surface tension, and ability to act as a solvent. It also causes ice to be less dense than liquid water.

**Question 3**:

How does water's high specific heat capacity affect Earth's climate?

- **Answer**: Water's high specific heat capacity means it can absorb and release large amounts of heat without changing temperature drastically. This helps regulate Earth's climate by absorbing heat in the summer and releasing it in the winter, moderating temperature changes and supporting life.

**Question 4**:

Discuss how the structure of a water molecule leads to its unique properties, such as cohesion and adhesion.

- **Answer**: The bent shape and polarity of water molecules cause them to stick to each other (cohesion) and to other surfaces (adhesion). Cohesion leads to surface tension, while adhesion allows water to cling to surfaces like plant tissues, helping it move through narrow spaces via capillary action.

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### 13. Extend (Beyond the Lesson)

To extend your understanding of water and its properties, try these additional tasks:

1. **Research Task**: Investigate how water is used in industrial processes and propose eco-friendly alternatives to reduce water pollution.

2. **Real-World Application**: Explore how water's properties are used in everyday products, such as cleaning agents or food preparation. How do these products utilize water's ability to dissolve substances?

3. **Challenge Question**: How might water behave differently on other planets with different atmospheric pressures and temperatures? What would happen to its boiling and freezing points?

**Spaced Practice**: Over the next week, revisit the concepts of water's polarity, hydrogen bonding, and its role as a solvent. Try explaining these concepts in your own words to a friend or family member. This will help reinforce your understanding and prepare you for future lessons on solutions and chemical reactions.