# 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 understanding their formulas is key to predicting 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:\*

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. Front airbags reduce driver fatalities in frontal crashes by 29% and fatalities of front-seat passengers aged 13 and older by 32%. Side airbags that protect the head reduce a car driver’s risk of death in driver-side crashes by 37% and an SUV driver’s risk by 52%. Overall, airbags can reduce passenger injuries by 50% in a car accident. In the event of a car crash, sensors trigger the airbags to deploy rapidly to cushion and protect passengers. The cushion is provided by gas that is rapidly released from a chemical reaction inside the airbag. The airbag inflates due to the gas from the chemical reaction. But the products of the chemical reaction should also be safe for passengers. For example, excess sodium metal can react violently with moisture in the air.

**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. Vocabulary:

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

- **Greek prefix:** A prefix derived from Greek that indicates 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 of a substance that includes water molecules, typically written as "compound · xH₂O," where "x" represents the number of water molecules.

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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 have a salt that looks dry, but when you heat it, water vapor escapes. This is because the water was hidden inside the salt’s structure. How can you figure out how much water was trapped in the salt?

**Hands-On Task: Hydrate Heating Experiment**

\*Materials:\*

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

- A heat source (Bunsen burner or hot plate)

- A crucible

- A balance

- Tongs

\*Procedure:\*

1. Weigh the crucible and record its mass.

2. Add a small amount of copper(II) sulfate pentahydrate to the crucible and weigh it again. Record the total mass.

3. Heat the crucible gently until the blue color of the copper(II) sulfate turns white or gray. This indicates that the water has been driven off.

4. Allow the crucible to cool and weigh it again. Record the mass of the anhydrous copper(II) sulfate.

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

\*Questions:\*

1. How much water was lost during heating?

2. What percentage of the original hydrate was water?

3. How does heating affect the structure of the hydrate?

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

**Prior Knowledge:**

- Understanding of chemical formulas and how to interpret them.

- Familiarity with the concept of mass and how to measure it.

- Basic knowledge of chemical reactions and the conservation of mass.

**Real-World Connection:**

Hydrates are all around us, from the salts we use in food to the compounds used in construction materials. For example, cement contains hydrates that help it harden when mixed with water. Understanding how hydrates work can help explain why certain materials behave the way they do when exposed to heat or moisture.

**Background Information:**

Water is a common participant in chemical reactions, but it doesn’t always act alone. In some compounds, water molecules are trapped inside the crystal structure of the substance. These compounds are called hydrates. The number of water molecules in a hydrate is always fixed and can be determined by heating the compound to remove the water. The remaining substance is called an anhydrous compound, meaning "without water."

In this lesson, the goal is to understand how to identify hydrates, how to calculate the amount of water they contain, and how they behave in chemical reactions. This knowledge is important for predicting the outcomes of reactions and for practical applications, such as designing materials that can absorb or release water.

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### 7. Explore (Hands-On Activity):

**Lab Activity: Determining the Formula of a Hydrate**

\*Materials:\*

- A sample of magnesium sulfate hydrate (MgSO₄ · xH₂O)

- A heat source

- A balance

- A crucible

- Tongs

\*Procedure:\*

1. Weigh the crucible and record its mass.

2. Add a sample of magnesium sulfate hydrate to the crucible and weigh it again. Record the total mass.

3. Heat the crucible until all the water is driven off (the sample will appear dry).

4. Allow the crucible to cool and weigh it again. Record the mass of the anhydrous magnesium sulfate.

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

6. Use the mass of the water and the mass of the anhydrous compound to determine the formula of the hydrate.

\*Questions:\*

1. What is the ratio of water to magnesium sulfate in the hydrate?

2. How does the formula of the hydrate compare to the formula of the anhydrous compound?

3. Why is it important to know the formula of a hydrate in chemical reactions?

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### 8. Explain (Lightbulb):

**Hydrates and Their Formulas**

Hydrates are compounds that contain water molecules within their structure. These water molecules are not just loosely attached; they are an integral part of the compound. The water in a hydrate is often referred to as "water of hydration." The formula of a hydrate is written as the formula of the compound followed by a dot and then the number of water molecules, like this: CuSO₄ · 5H₂O. This means that for every one formula unit of copper(II) sulfate, there are five water molecules.

**Anhydrous Compounds**

When a hydrate is heated, the water molecules are released as vapor, leaving behind the anhydrous form of the compound. For example, if you heat copper(II) sulfate pentahydrate (CuSO₄ · 5H₂O), the water is driven off, and you are left with anhydrous copper(II) sulfate (CuSO₄).

**Greek Prefixes in Hydrates**

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

- Mono- means one (e.g., Na₂CO₃ · H₂O is sodium carbonate monohydrate).

- Di- means two (e.g., CaSO₄ · 2H₂O is calcium sulfate dihydrate).

- Tri- means three (e.g., AlCl₃ · 3H₂O is aluminum chloride trihydrate).

**Calculating the Percent by Mass of Water in a Hydrate**

To calculate the percent by mass of water in a hydrate, you need to know the mass of the water and the mass of the entire hydrate. The formula is:

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

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For example, if you have a hydrate that weighs 10 grams and loses 3 grams of water when heated, the percent by mass of water is:

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\frac{3}{10} \times 100 = 30\%

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**Predicting Reactions Involving Hydrates**

When hydrates are involved in chemical reactions, the water of hydration must be accounted for. For example, when copper(II) sulfate pentahydrate reacts with another substance, the reaction will include both the copper(II) sulfate and the water molecules. If the hydrate is heated first, the water will be driven off, and only the anhydrous compound will react.

**Factors Affecting Percent Yield**

In real-world chemical reactions, the actual yield of a product is often less than the theoretical yield. This is because of factors like incomplete reactions, side reactions, and loss of material during the process. When hydrates are involved, the amount of water lost during heating can also affect the percent yield. If not all the water is driven off, the mass of the product will be higher than expected, leading to a lower percent yield.

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### 9. Elaborate (Deep Dive):

**Real-World Example: Hydrates in Construction**

One important application of hydrates is in the construction industry. Cement contains calcium sulfate dihydrate (CaSO₄ · 2H₂O), which helps control the setting time of concrete. When water is added to cement, the hydrate reacts and hardens, forming a solid structure. Understanding the role of hydrates in this process is crucial for ensuring that buildings and roads are strong and durable.

**Sample Problem:**

A sample of barium chloride dihydrate (BaCl₂ · 2H₂O) weighs 20 grams. After heating, the anhydrous barium chloride weighs 16 grams. What is the percent by mass of water in the hydrate?

**Solution:**

1. Mass of water = 20 g (hydrate) - 16 g (anhydrous) = 4 g

2. Percent by mass of water = (4 g / 20 g) × 100 = 20%

**Practice Question:**

A sample of magnesium sulfate heptahydrate (MgSO₄ · 7H₂O) weighs 30 grams. After heating, the anhydrous magnesium sulfate weighs 15 grams. What is the percent by mass of water in the hydrate?

\*Answer:\* 50%

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### 10. Evaluate (Check for Understanding):

**Assessment Questions:**

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

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

3. Why is it important to account for the water in a hydrate during a chemical reaction?

**Answers:**

1. A hydrate contains water molecules within its structure, while an anhydrous compound does not.

2. Percent by mass of water = (Mass of water / Mass of hydrate) × 100.

3. The water in a hydrate can affect the outcome of a chemical reaction, so it must be included in calculations.

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This structured lesson plan covers the key concepts of hydrates, their formulas, and their reactions, while encouraging hands-on learning and critical thinking about real-world applications.

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

Here are three questions to check your understanding of the key concepts we covered in the "Explain" section. Try to answer them on your own first, then check the answers below.

1. **What is the atomic number of an element?**

- \*Answer:\* The atomic number is the number of protons in the nucleus of an atom. It helps identify the element.

2. **Why are noble gases considered stable?**

- \*Answer:\* Noble gases are considered stable because they have a full outer electron shell. This makes them unlikely to react with other elements.

3. **Explain how ionic bonds are formed between atoms.**

- \*Answer:\* Ionic bonds are formed when one atom gives up one or more electrons to another atom. This usually happens between a metal and a non-metal. The metal becomes a positively charged ion, and the non-metal becomes a negatively charged ion. The opposite charges attract, creating the bond.

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### 11. Elaborate (Power Up)

To deepen your understanding, let's explore these questions:

1. **Why do some elements form covalent bonds instead of ionic bonds?**

- \*Answer:\* Some elements form covalent bonds because they have similar tendencies to gain or lose electrons. In covalent bonds, atoms share electrons to achieve a full outer shell, rather than transferring them like in ionic bonds.

2. **How would 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 also do not conduct electricity when dissolved in water, unlike ionic compounds, which can conduct electricity when dissolved.

3. **Can you think of a real-world example where understanding chemical bonding is important?**

- \*Answer:\* Understanding chemical bonding is important in medicine. For example, knowing how different atoms bond can help scientists design drugs that interact with specific molecules in the body, improving treatment for diseases.

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### 12. Final Evaluation

**Debate Question:**

**Should scientists focus more on developing new synthetic materials or on improving natural materials for use in everyday products?**

- **Arguments for synthetic materials:** Synthetic materials can be designed to have specific properties, like being lightweight, strong, or resistant to heat. They can also be produced in large quantities and tailored for specific uses.

- **Arguments for natural materials:** Natural materials are often biodegradable and less harmful to the environment. They can be renewable and have been used successfully for thousands of years.

**MCQ Question:**

Which of the following is an advantage of using synthetic materials over natural materials?

a) They are always cheaper to produce.

b) They can be designed with specific properties.

c) They are always better for the environment.

d) They are more biodegradable.

- \*Answer:\* **b) They can be designed with specific properties.**

- \*Explanation:\* Synthetic materials can be engineered to have properties that are not found in natural materials, such as being more durable or heat-resistant.

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**ACT Multiple-Choice Questions:**

1. **How does the atomic structure of metals contribute to their ability to conduct electricity?**

Metals have free-moving electrons that allow them to conduct electricity. These electrons can move easily through the metal when a voltage is applied.

**MCQ:**

Which part of a metal atom is responsible for its ability to conduct electricity?

a) Protons

b) Neutrons

c) Electrons

d) Nucleus

- \*Answer:\* **c) Electrons**

- \*Explanation:\* The free-moving electrons in metals are what allow them to conduct electricity.

2. **What happens to the electrons in a covalent bond?**

In a covalent bond, atoms share electrons to achieve a full outer shell. This sharing allows both atoms to become more stable.

**MCQ:**

In a covalent bond, electrons are:

a) Transferred from one atom to another

b) Shared between two atoms

c) Lost by both atoms

d) Gained by both atoms

- \*Answer:\* **b) Shared between two atoms**

- \*Explanation:\* In covalent bonding, atoms share electrons to fill their outer electron shells.

3. **Why do ionic compounds tend to have high melting and boiling points?**

Ionic compounds have strong attractions between the positive and negative ions, which require a lot of energy to break apart.

**MCQ:**

Ionic compounds have high melting points because:

a) They are made of metals.

b) The ions are strongly attracted to each other.

c) They are made of covalent bonds.

d) They are gases at room temperature.

- \*Answer:\* **b) The ions are strongly attracted to each other.**

- \*Explanation:\* The strong electrostatic forces between positive and negative ions require a lot of energy to overcome.

4. **Why do noble gases rarely form compounds?**

Noble gases have a full outer electron shell, making them stable and unreactive.

**MCQ:**

Noble gases rarely form compounds because:

a) They have low atomic numbers.

b) They have full outer electron shells.

c) They are metals.

d) They are radioactive.

- \*Answer:\* **b) They have full outer electron shells.**

- \*Explanation:\* Having a full outer shell means noble gases do not need to gain, lose, or share electrons, making them chemically stable.

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**Long-Answer Questions:**

1. **Explain the difference between ionic and covalent bonding. Provide examples of each.**

- \*Answer:\* Ionic bonding occurs when one atom transfers electrons to another atom, typically between a metal and a non-metal. For example, sodium chloride (NaCl) forms when sodium gives up an electron to chlorine. Covalent bonding happens when two atoms share electrons, usually between non-metals. An example of a covalent bond is water (H₂O), where hydrogen and oxygen share electrons.

2. **Describe how the periodic table is organized and explain the significance of groups and periods.**

- \*Answer:\* The periodic table is organized by increasing atomic number. Elements in the same group (vertical columns) have similar chemical properties because they have the same number of valence electrons. Elements in the same period (horizontal rows) have the same number of electron shells but different numbers of valence electrons.

3. **What is electronegativity, and how does it affect the type of bond formed between two atoms?**

- \*Answer:\* Electronegativity is the ability of an atom to attract electrons. When two atoms have a large difference in electronegativity, an ionic bond is likely to form because one atom will transfer electrons to the other. When the difference is smaller, a covalent bond is more likely, as the atoms will share electrons.

4. **How do the properties of metals and non-metals differ, and how are these differences related to their atomic structure?**

- \*Answer:\* Metals tend to be shiny, malleable, and good conductors of heat and electricity. This is because their atoms have free-moving electrons. Non-metals, on the other hand, are often brittle, dull, and poor conductors. This is because their electrons are more tightly bound to the nucleus, making them less able to move freely.

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### 13. Extend (Beyond the Lesson)

To extend your learning, consider these activities:

1. **Research Task:** Investigate how the development of new materials, such as graphene, could change technology in the future. Write a short report on how graphene's properties could be applied in electronics or medicine.

2. **Real-World Application:** Think about how knowledge of chemical bonding is used in environmental science. How could understanding the bonds between atoms help scientists develop better ways to clean up pollution or create more sustainable energy sources?

3. **Spaced Practice:** Over the next few days, revisit the concepts of ionic and covalent bonding. Try drawing diagrams of different molecules and compounds, showing how the atoms bond together. This will help reinforce your understanding of how chemical bonds form.

4. **Next Topic Hint:** In the next lesson, we will explore chemical reactions, including how bonds break and form during reactions. We'll also learn about the conservation of mass and how to balance chemical equations.