Unit 3: Chemical Reactions and Stoichiometry

## Chapter 10: Stoichiometry

# Lesson 4: Hydrates: Their Formulas and Reactions

### 1. Big Idea:

Hydrates are compounds that contain water molecules within their structure, and understanding their composition is key to predicting their behavior in chemical reactions.

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### 2. Essential Questions:

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

Hydrates form when water molecules become part of a compound's crystal structure. We can determine their composition by analyzing the ratio of water to the rest of the compound. This can be done through experiments that involve heating the hydrate to remove the water and measuring the mass before and after heating.

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### 3.1 Phenomenon-Based Learning:

The lesson builds upon the chapter's storyline by introducing hydrates, a specific type of compound where water is part of the chemical formula. The phenomenon explored in this lesson is how water can be integrated into compounds and how this affects chemical reactions. This connects to the larger unit phenomenon of how chemical reactions can improve safety features, such as airbags in cars, which rely on controlled chemical reactions.

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### 3.2 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 into their formula! These are called hydrates. How would hydrates affect a chemical reaction? How should they be counted?

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### 4. Vocabulary:

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

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

- **Hydrates**: Compounds that contain water molecules within their crystal 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:**

Water is a part of many chemical reactions. But what happens when water is part of a compound’s formula? How does this affect the reaction? Let's explore this by heating a hydrate and observing what happens to the water in its structure.

**Mini Task:**

Take a small sample of a known hydrate (e.g., copper(II) sulfate pentahydrate) and heat it in a crucible. Observe the changes in color and mass as the water is driven off.

**Materials:**

- Copper(II) sulfate pentahydrate

- Crucible

- Bunsen burner

- Balance

- Tongs

**Procedure:**

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

2. Heat the sample in a crucible over a Bunsen burner until the color changes from blue to white, indicating the water has been removed.

3. Allow the crucible to cool and reweigh the sample.

4. Calculate the mass of water lost.

**Follow-up Questions:**

1. What happened to the color of the copper(II) sulfate after heating?

**Answer:** The color changed from blue to white because the water molecules were removed.

2. How much mass was lost after heating?

**Answer:** The mass lost corresponds to the water that was part of the hydrate.

3. How can we calculate the percentage of water in the original hydrate?

**Answer:** By dividing the mass of water lost by the original mass of the hydrate and multiplying by 100.

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

**Background Information:**

In everyday life, we encounter hydrates in various forms. For example, Epsom salts (magnesium sulfate heptahydrate) are used in baths to soothe muscles. When heated, these salts lose water and become anhydrous, changing their properties. This is similar to what happens in many industrial processes where hydrates are used and then heated to release water.

**Discussion Prompt:**

What other substances might contain water as part of their structure? How could this water affect the way these substances behave in chemical reactions?

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

1. **What is a hydrate?**

**Answer:** A hydrate is a compound that contains water molecules within its crystal structure.

2. **What happens to a hydrate when it is heated?**

**Answer:** When heated, the water molecules are released, leaving behind an anhydrous compound.

3. **How can we determine the amount of water in a hydrate?**

**Answer:** By measuring the mass before and after heating and calculating the difference, which represents the mass of the water.

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### 9. Explain (Lightbulb):

Hydrates are compounds that include water molecules as part of their structure. These water molecules are not just loosely attached; they are an integral part of the compound’s crystal lattice. The number of water molecules associated with each formula unit of the compound is indicated by a Greek prefix in the chemical formula. For example, copper(II) sulfate pentahydrate has the formula CuSO₄·5H₂O, indicating that for every formula unit of CuSO₄, there are five water molecules.

### # \*\*How Hydrates Form:\*\*

Hydrates form when ionic compounds crystallize from water solutions. As the compound forms crystals, water molecules get trapped in the spaces between the ions. These water molecules are held in place by weak forces, such as hydrogen bonding, but they are still an essential part of the compound's structure.

### # \*\*Analyzing Hydrates:\*\*

To analyze a hydrate, we can heat it to drive off the water, leaving behind the anhydrous form of the compound. By measuring the mass before and after heating, we can determine how much water was in the hydrate. This allows us to calculate the percent by mass of water in the compound.

**Sample Problem:**

A sample of magnesium sulfate heptahydrate (MgSO₄·7H₂O) weighs 4.93 g. After heating, the anhydrous magnesium sulfate weighs 2.40 g. Calculate the percent by mass of water in the hydrate.

**Solution:**

1. Mass of water = 4.93 g (hydrate) - 2.40 g (anhydrous compound) = 2.53 g

2. Percent by mass of water = (2.53 g / 4.93 g) × 100 = 51.3%

**Progress Check:**

A sample of calcium chloride dihydrate (CaCl₂·2H₂O) weighs 5.00 g. After heating, the anhydrous calcium chloride weighs 3.33 g. Calculate the percent by mass of water in the hydrate.

**Answer:**

Mass of water = 5.00 g - 3.33 g = 1.67 g

Percent by mass of water = (1.67 g / 5.00 g) × 100 = 33.4%

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

When hydrates are involved in chemical reactions, the water they contain must be accounted for. For example, if a hydrate is heated, the water will be released as steam, and the remaining anhydrous compound may react differently than the hydrate. This is important in industries where precise amounts of chemicals are needed for reactions.

**Sample Problem:**

What is the product of heating barium chloride dihydrate (BaCl₂·2H₂O)?

**Solution:**

When heated, barium chloride dihydrate will lose its water molecules, leaving anhydrous barium chloride (BaCl₂) as the product.

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

In any chemical reaction, the percent yield is the ratio of the actual yield (what you get in the lab) to the theoretical yield (what you expect based on calculations). Several factors can affect the percent yield in reactions involving hydrates:

- **Incomplete Reaction:** If not all the water is driven off, the yield of the anhydrous compound will be lower.

- **Side Reactions:** Water released from the hydrate might react with other substances, affecting the overall yield.

- **Measurement Errors:** Inaccurate measurements of mass before and after heating can lead to incorrect calculations of yield.

**Sample Problem:**

In an experiment, 10.0 g of copper(II) sulfate pentahydrate (CuSO₄·5H₂O) was heated, and 6.4 g of anhydrous copper(II) sulfate (CuSO₄) was obtained. Calculate the percent yield if the theoretical yield of CuSO₄ is 6.8 g.

**Solution:**

Percent yield = (6.4 g / 6.8 g) × 100 = 94.1%

**Progress Check:**

In an experiment, 12.0 g of magnesium sulfate heptahydrate (MgSO₄·7H₂O) was heated, and 5.8 g of anhydrous magnesium sulfate (MgSO₄) was obtained. Calculate the percent yield if the theoretical yield is 6.0 g.

**Answer:**

Percent yield = (5.8 g / 6.0 g) × 100 = 96.7%

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### Conclusion:

Hydrates are an important class of compounds that contain water molecules within their structure. By heating hydrates, we can remove the water and study the anhydrous form of the compound. Understanding hydrates is essential for predicting the outcomes of reactions and calculating the percent yield in experiments.

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

1. **What is the atomic number of an element and why is it important?**

**Answer:** The atomic number is the number of protons in the nucleus of an atom. It is important because it defines the element and determines its position on the periodic table.

2. **How does the arrangement of electrons in an atom affect its chemical properties?**

**Answer:** The arrangement of electrons, especially in the outermost shell (valence electrons), determines how an atom interacts with other atoms. This affects its reactivity and the types of bonds it can form.

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

**Answer:** Ionic bonds form when one atom donates an electron to another, creating charged ions that attract each other. Covalent bonds form when atoms share electrons to achieve stability.

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### 11. Elaborate (Power Up)

1. **Mini-task:** Draw a diagram of a sodium atom and a chlorine atom before and after they form an ionic bond. Label the electrons and show how they are transferred.

- **Answer:** Sodium has 11 electrons, and chlorine has 17 electrons. Sodium donates one electron to chlorine, making sodium a positive ion (Na+) and chlorine a negative ion (Cl-). The transfer of the electron creates an ionic bond.

2. **Open-ended question:** How would the properties of a molecule change if it had polar covalent bonds instead of nonpolar covalent bonds?

- **Answer:** In polar covalent bonds, electrons are shared unequally, creating partial charges on the atoms. This can lead to different physical properties, such as higher boiling points, and can affect how the molecule interacts with other substances, like water.

3. **Additional question:** How do you think the periodic table helps scientists predict the behavior of elements in chemical reactions?

- **Answer:** The periodic table organizes elements by their atomic number and electron configuration, which helps scientists predict how elements will react based on their position. Elements in the same group often have similar properties and reactivity.

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### 12. Final Evaluation

**Debate Question:**

"Should we focus more on developing new synthetic materials or on improving the sustainability of natural materials?"

- **Argument for synthetic materials:** Synthetic materials can be engineered to have specific properties, such as strength, flexibility, or resistance to heat. This can lead to innovations in technology and medicine.

- **Argument for natural materials:** Natural materials are often more biodegradable and environmentally friendly. Focusing on sustainability could reduce pollution and conserve resources.

**MCQ Question:**

Which of the following is an example of a covalent bond?

A) NaCl

B) H2O

C) MgO

D) KBr

**Answer:** B) H2O

**Explanation:** Water (H2O) is formed by covalent bonds, where hydrogen and oxygen share electrons.

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**ACT Multiple-Choice Questions:**

1. **Paragraph:** When sodium (Na) reacts with chlorine (Cl), sodium loses one electron to become a positive ion (Na+), and chlorine gains that electron to become a negative ion (Cl-). These oppositely charged ions attract each other, forming an ionic bond.

**Question:** What happens to the electron configuration of sodium after it forms an ionic bond with chlorine?

A) Sodium gains an electron and becomes stable.

B) Sodium loses an electron and becomes stable.

C) Sodium shares an electron with chlorine.

D) Sodium loses two electrons and becomes unstable.

**Answer:** B) Sodium loses an electron and becomes stable.

**Explanation:** Sodium loses one electron to achieve a stable electron configuration, similar to the noble gas neon.

2. **Paragraph:** Covalent bonds can be polar or nonpolar. In a polar covalent bond, electrons are shared unequally between two atoms, while in a nonpolar covalent bond, electrons are shared equally.

**Question:** Which of the following molecules is most likely to have a polar covalent bond?

A) O2

B) H2

C) CO2

D) HCl

**Answer:** D) HCl

**Explanation:** HCl has a polar covalent bond because chlorine is more electronegative than hydrogen, causing unequal sharing of electrons.

3. **Paragraph:** The periodic table is arranged so that elements with similar properties are in the same group. For example, alkali metals in Group 1 are highly reactive with water.

**Question:** Which of the following elements would you expect to react most similarly to sodium (Na)?

A) Magnesium (Mg)

B) Potassium (K)

C) Aluminum (Al)

D) Calcium (Ca)

**Answer:** B) Potassium (K)

**Explanation:** Potassium is in the same group as sodium (Group 1), so it has similar chemical properties and reactivity.

4. **Paragraph:** Ionic compounds, like sodium chloride (NaCl), have high melting points and conduct electricity when dissolved in water. Covalent compounds, like sugar, do not conduct electricity when dissolved in water.

**Question:** Why do ionic compounds conduct electricity in water?

A) They dissolve into molecules that can move freely.

B) They dissolve into charged ions that can move freely.

C) They share electrons with water molecules.

D) They form neutral molecules that conduct electricity.

**Answer:** B) They dissolve into charged ions that can move freely.

**Explanation:** Ionic compounds dissociate into charged ions in water, which allows them to conduct electricity.

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**Long-Answer Questions:**

1. **Explain how the periodic table is organized and how this organization helps predict the properties of elements.**

**Answer:** The periodic table is organized by increasing atomic number. Elements in the same group have similar chemical properties because they have the same number of valence electrons. The table is divided into metals, nonmetals, and metalloids, which helps predict how elements will behave in chemical reactions.

2. **Describe the difference between an ionic bond and a covalent bond. Provide an example of each.**

**Answer:** An ionic bond forms when one atom donates an electron to another, creating charged ions (e.g., NaCl). A covalent bond forms when two atoms share electrons (e.g., H2O). Ionic bonds typically form between metals and nonmetals, while covalent bonds form between nonmetals.

3. **How do valence electrons determine the reactivity of an element? Give an example.**

**Answer:** Valence electrons are the outermost electrons and are involved in chemical reactions. Elements with a nearly full or nearly empty outer shell are more reactive. For example, sodium (Na) has one valence electron, making it highly reactive, while neon (Ne) has a full outer shell, making it unreactive.

4. **Why are noble gases considered stable, and how does this stability affect their chemical behavior?**

**Answer:** Noble gases have a full outer electron shell, which makes them stable and unreactive. This stability means they do not easily form compounds with other elements because they do not need to gain, lose, or share electrons.

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### 13. Extend (Beyond the Lesson)

1. **Additional Task:** Research how the discovery of new elements has impacted modern technology. Write a short report on how a specific element, such as silicon or lithium, is used in everyday products.

- **Answer:** Silicon is used in electronics, especially in semiconductors, which are essential for computers and smartphones. Lithium is used in rechargeable batteries, which power many of today’s portable devices.

2. **Challenge Question:** How might the development of new synthetic materials change the future of medicine or construction?

- **Answer:** New synthetic materials could lead to stronger, lighter, and more durable medical devices, such as artificial joints or biodegradable implants. In construction, materials that are more resistant to weathering or that are self-repairing could make buildings last longer and require less maintenance.

3. **Spaced Practice:** Over the next week, revisit the concepts of ionic and covalent bonding by creating flashcards. On one side, write the name of a compound, and on the other side, write whether it has ionic or covalent bonds.