Hydrates

Unit: Moles

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS1-2, HS-PS1-3

Mastery Objective(s): (Students will be able to…)

- Determine the number of water molecules in a hydrate

Success Criteria:

- Empirical formula is calculated correctly (if necessary).
- Number of water molecules in each formula unit is calculated correctly.
- Formula of hydrate is written correctly, with the empirical first, then a dot, then the number of H_2O molecules.
- Algebra and rounding to appropriate number of significant figures is correct.

Tier 2 Vocabulary: hydrate

Language Objectives:

- Explain the concept of a hygroscopic compound.
- Explain the process of determining the amount of water in a hydrate, both numerically and experimentally.

Notes:

hydrate: an ionic solid that has H_2O molecules loosely bound to its crystals.

water of hydration: the water molecules that are bound into a hydrate.

anhydrous: a compound that has had its water of hydration removed, usually by heating.

hygroscopic: a compound that can absorb water from the air. In a humid environment, an anhydrous compound will absorb water until it becomes the hydrate.

Naming of Hydrates

The name of a hydrate is the name of the compound followed by a number prefix and the word "hydrate".

The number prefix (the same ones we used for molecular compounds; found in "Table J. Number Prefixes" on page 540 of your Chemistry Reference Tables) indicates the number of H_2O molecules in the hydrate. For example, the compound nickel (II) chloride forms a hydrate that contains six water molecules. Its name is therefore:

nickel (II) chloride hexahydrate

Use this space for summary and/or additional notes:

Chemical Formula of a Hydrate

The chemical formula of a hydrate is the chemical formula of the compound followed by a dot and the number of H_2O molecules bound to it. For example, the chemical formula of nickel (II) chloride hexahydrate is:

$$NiCl_2 \cdot 6\ H_2O$$

Molar Mass of a Hydrate

The molar mass of a hydrate includes the mass of the water of hydration. This means a hydrate will have a larger molar mass than the anhydrous compound. For example, the molar mass of $NiCl_2$ is 129.60 g. The molar mass of H_2O is 18.015 g. The molar mass of 6 H_2O molecules is $6 \times 18.015 = 108.09$ g.

Therefore, the molar mass of $NiCl_2 \cdot 6\ H_2O$ is $129.60 + 108.09 = 237.69$ g

Experimentally Determining the Water of Hydration

You can figure out the formula of a hydrate by weighing it, heating it to remove the water of hydration, and figuring out how many moles of water were removed for every mole of the compound.

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Sample Problem:

Q: Sodium sulfate forms a hydrate. We want to find the chemical formula of the hydrate. Suppose you weighed out 32.22 g of the hydrate. After heating it to remove all of the water, the final mass was 14.20 g.

A: The formula of anhydrous sodium sulfate is Na_2SO_4, which has a molar mass of 142.05 g. We have:

$$\frac{14.20\,\text{g}\,Na_2SO_4}{1} \times \frac{1\,\text{mol}\,Na_2SO_4}{142.05\,\text{g}\,Na_2SO_4} = 0.10\,\text{mol}\,Na_2SO_4$$

The amount of water removed was 32.22 − 14.20 = 18.02 g.

This 18.02 g of H_2O is:

$$\frac{18.02\,\text{g}\,H_2O}{1} \times \frac{1\,\text{mol}\,H_2O}{18.0152\,\text{g}\,H_2O} = 1.000\,\text{mol}\,H_2O$$

Our sample had 1 mole of H_2O and 0.1 mole of Na_2SO_4. This is 10 times as much H_2O as Na_2SO_4:

$$\frac{1\,\text{mol}\,H_2O}{0.1\,\text{mol}\,Na_2SO_4} = \frac{10\,H_2O}{1\,Na_2SO_4}$$

Therefore, the formula must be:

$$Na_2SO_4 \cdot 10\ H_2O$$

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Homework Problems

1. What is the chemical formula of iron (III) chloride hexahydrate?

2. Give the stock name and molar mass of the compound $CoSO_4 \cdot 7\,H_2O$?

3. If 10.0 g of $Na_2CrO_4 \cdot 4\,H_2O$ is heated to constant mass (*i.e.,* until all of the water of hydration is removed), what will the final mass be?
   a. Find the molar mass of $Na_2CrO_4 \cdot 4\,H_2O$.

   b. Find the number of moles of $Na_2CrO_4 \cdot 4\,H2O$ in 10.0 g.

   c. Find the molar mass of anhydrous Na_2CrO_4.

   d. Convert the number of moles (*which you found in part b*) to grams, using the molar mass of the anhydrous compound (*which you found in part c*).

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3. 14.70 g of a hydrate of $CaCl_2$ is heated to dryness. The anhydrous sample has a mass of 11.10 g after evaporating the H_2O. Use the following steps to determine the chemical formula of the hydrate.

   a. Find the moles of anhydrous compound left at the end.

   b. Find the moles of water evaporated. (You'll need to find the grams of water evaporated, and then convert to moles.)

   c. Find the ratio of the moles of water evaporated to the moles of the anhydrous compound. This will be the number of water molecules in the hydrate.

   d. Write the formula for the hydrate (*using the number of water malecules that you found in part c*)?

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