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Hydrates: Determining the Chemical Formula From Empirical Data

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Learn the definition of a hydrate and an anhydrate in this lesson. Discover how, when given experimental data, you can determine the formula of a hydrate by following simple steps that include finding the moles of hydrate and anhydrate and comparing the two to write the formula.

Hydrates

'Ah, I need to hydrate!' Everyone knows what it means to hydrate. To hydrate means to drink, but it can also mean to 'combine chemically with water.' Although we use the word hydrate in our everyday lives, it's actually a chemistry term.

A **hydrate** is a compound that contains water with a definite mass in the form of H₂O. Hydrates are often in the form of a crystal that can be heated and the water can be 'burned off' by turning it into steam. This usually causes the hydrate to lose its crystalline structure. The substance that is left over after the hydrate has lost its water is called an **anhydrate**. By measuring the compound before heating and after, the amount of water in the original hydrate can be determined and the formula discovered.

Unknown hydrates are written with their base form; then an '*n*' is placed before the H₂O. The '*n*' before the H₂O means there is a number there, but we don't know what it is yet, such as in MgSO₄ *n*H₂O for a magnesium sulfate hydrate or Na₂CO₃ *n*H₂O for a sodium carbonate hydrate. Luckily for us, this is an easy determination. Finding '*n*' is fun!

Steps to Finding the Formula of a Hydrate

Here are the steps to finding the formula of a hydrate:

1. Determine the mass of the water that has left the compound. This allows us to determine the mass of water that was in the hydrate and the mass of the anhydrate. We do this by subtracting the mass of the anhydrate from the mass of the hydrate. This equals the mass of water.
2. Convert the mass of water to moles. To do this, we divide mass of water by the molar mass of water to get moles of water. Remember that the units for molar mass are g/mol.

When we divide mass (in g) by molar mass (g/mol), grams will cancel out and we will be left with moles.

3. Convert the mass of anhydrate that is left over to moles. To do this, we divide the mass of anhydrate by the molar mass of anhydrate to get the moles of anhydrate.
4. Find the water-to-anhydrate mole ratio. Generally, you will have more waters than anhydrate, so divide the moles of water by the moles of anhydrate. This gives you your mole ratio (a note about this step: if your calculations give you a number that is very close to a whole integer, it's generally safe to round to the nearest whole one. If your number has a decimal that is close to .33, .5, or .66, you need to find the lowest common multiple of that number that is a whole number and apply it to the entire formula).
5. Use the mole ratio to write the formula.

Let's see how these steps work with a sample problem:

A 210.4 g hydrate of Epsom salt, $\text{MgSO}_4 \cdot n\text{H}_2\text{O}$ was heated up, the water was released, and the final anhydrate mass was 120.4 g. What is the formula of this hydrate?

1. Determine the mass of the water that has left the compound. Take the mass of the hydrate and subtract the mass of anhydrate from that to get the mass of water. $210.4 \text{ g MgSO}_4 \cdot n\text{H}_2\text{O} - 120.4 \text{ g MgSO}_4 = 90 \text{ g H}_2\text{O}$.
2. Convert the mass of water to moles. Mass of water / molar mass of water = moles of water. $90 \text{ g H}_2\text{O} / (18 \text{ g/mol H}_2\text{O}) = 5 \text{ moles H}_2\text{O}$.
3. Convert the mass of anhydrate that is left over to moles. Mass of anhydrate / molar mass of anhydrate = moles of anhydrate. $120.4 \text{ g MgSO}_4 / (120.4 \text{ g/mol MgSO}_4) = 1 \text{ mole MgSO}_4$.
4. Find the water-to-anhydrate mole ratio. Divide moles of water by moles of anhydrate to get the mole ratio. $5 \text{ moles H}_2\text{O} / 1 \text{ mole MgSO}_4 = 5:1$.
5. Use the mole ratio to write the formula. Since there are 5 moles of H_2O for every 1 mole of MgSO_4 , the formula is $\text{MgSO}_4 \cdot 5\text{H}_2\text{O}$.

Example One

Are you ready for another example? Feel free to pause the video at any point to do your own calculations:

A hydrate of sodium carbonate, $\text{Na}_2\text{CO}_3 \cdot n\text{H}_2\text{O}$, originally contains 17.70 g. After heating, its final weight is 15.10 g. What is its formula?

1. Take the mass of the hydrate and subtract the mass of the anhydrate to get the mass of water. $17.70 \text{ g Na}_2\text{CO}_3 \cdot n\text{H}_2\text{O} - 15.10 \text{ g Na}_2\text{CO}_3 = 2.60 \text{ g H}_2\text{O}$.
2. Divide the mass of water by the molar mass of water to get moles of water. $2.60 \text{ g H}_2\text{O} / (18.00 \text{ g/mol H}_2\text{O}) = 0.144 \text{ moles H}_2\text{O}$.
3. Divide the mass of anhydrate by the molar mass of anhydrate to get moles of anhydrate. $15.1 \text{ g Na}_2\text{CO}_3 / (106 \text{ g/mol Na}_2\text{CO}_3) = 0.142 \text{ moles Na}_2\text{CO}_3$.
4. Divide moles of water by the moles of anhydrate to get the mole ratio. $0.144 \text{ moles H}_2\text{O} / 0.142 \text{ moles Na}_2\text{CO}_3 = 1.01:1$. It is safe to round this to a 1:1 ratio.

5. Use the mole ratio to write the formula. Since there is only 1 mole of H₂O for every 1 mole of Na₂CO₃, the mole ratio is 1:1 and the formula is Na₂CO₃ · H₂O.