# The Formula of a Hydrate (F 18)

## Hydrates, Hydroxides, and Hydrous Oxides

A hydrate is a solid crystalline substance, either ionic or covalent, that contains water as an essential part of its crystal lattice. The water molecules are always present in a definite proportion, relative to the other molecules or ions, and are a part of the formula of the substance. The water molecules may be closely associated with one or another of the ions in an ionic substance, or may occupy some other definite position in the crystal structure.

We should distinguish between a hydrate such as gypsum, $CaSO_4{\cdot}2\ H_2O$, and a metallic hydroxide, such as $Ca(OH)_2$. The latter formula could be written $CaO{\cdot}H_2O$, but since it is a basic substance whose aqueous solution contains hydroxide ions, the formula $Ca(OH)_2$ is correct.

Some oxides, such as $Fe_2O_3$, form hydrates with varying amounts of water. The resulting product, ordinary rust, has an indefinite formula and is more correctly written $Fe_2O_3{\cdot}x\ H_2O$. $Fe(OH)_3$ would indicate a definite formula. Hydrated oxides with indefinite formulas are called hydrous oxides. However, chemists sometimes use the less correct formula $Fe(OH)_3$ for such a hydrated iron oxide as $Fe_2O_3{\cdot}3\ H_2O$ , iron (III) oxide trihydrate. Another example would be the less correct formula $Fe(OH)_2$ for such a hydrated iron oxide as $FeO{\cdot}H_2O$, iron (II) oxide monohydrate. An anhydrate contains no waters of hydration such as $Fe_2O_3$, iron (III) oxide anhydrous

If a hydrate is put into a closed container, water molecules will dissociate from the crystal surfaces and evaporate into the surrounding space until the concentration of vaporous water molecules increases to the point at which they are returning to the crystal at the same rate they are leaving. That is, a steady state of opposing tendencies (an equilibrium) results. This is dependent upon the partial pressure of water in the atmosphere, also measured as % humidity. Waters of hydration will often increase with increasing humidity. This is illustrated in the following example where the amount of hydrate is dependent upon the water vapor pressure, an increase in humidity will shift the equilibrium to the left

$$Fe(NO_3)_3{\cdot}9\ H_2O \quad \text{<-->} \quad Fe(NO_3)_3 \quad + \quad 9\ H_2O_{(g)}$$

For some hydrates, such as $Na_2SO_4{\cdot}10\ H_2O$, the tendency to lose water is quite large and it will give a high vapor pressure in a closed container. $Na_2SO_4{\cdot}10\ H_2O$ therefore tends to effloresce (lose water) in most ordinary atmospheric conditions, in which the water vapor pressure is less than this equilibrium value. For others, such as $CaSO_4{\cdot}2\ H_2O$, it is very small and a low vapor pressure is observed.

Gypsum, $CaSO_4{\cdot}2\ H_2O$, has a very low vapor pressure or tendency to evaporate water molecules. Therefore, the anhydrous salt, $CaSO_4$ (commercially called Drierite), readily absorbs water from the surrounding materials in contact with it to form the hydrate and is often used as a drying agent (or dessicant). The gain of water is called deliquescence.

When a hydrate is heated, the tendency for it to lose water is increased. Most hydrates can be dehydrated completely to the anhydrous form simply by heating them. We will carry out a quantitative dehydration for one or more hydrates in order to determine the moles of water of hydration per mole of anhydrous salt. This will give us the formula of the hydrate.

# EXPERIMENTAL PROCEDURE

**1.a. Efflorescence and Deliquescence.** Expose several pieces each of $CuSO_4 \cdot 5\ H_2O$, $Na_2SO_4 \cdot 10\ H_2O$, $CoCl_2 \cdot 6\ H_2O$, NaOH, and anhydrous $CaCl_2$, to the atmosphere by placing them in uncovered watch glasses, evaporating dishes, or beakers. Your Instructor may do this for you. Observe any changes at the end of the laboratory period and write down the % humidity in the room.

**1.b. Effect of a Drying Agent.** Make a dessicator using a test tube as follows. Place about a centimeter depth of anhydrous $CaSO_4$ (Drierite), or 4-mesh anhydrous $CaCl_2$, into a 15 cm test tube and at once close it with a rubber stopper. Holding the test tube horizontally, open it just long enough to insert near the open end several crystals of the hydrated salts used in 2.a. Leave the test tube horizontal. Your Instructor may do this for you. Observe the results at the end of the laboratory period.

**2. The Formula of a Hydrate.**

1. Heat a clean crucible + lid for about 2 minutes to dry thoroughly. When completely cool, weigh to the nearest mg, ± 0.001 g.
2. Add approximately 3 g of an unknown hydrate into the crucible and reweigh.
3. Heat the contents by placing on a clay triangle supported by a ring clamp. Heat using a gentle Bunsen flame at no time permit the crucible to become red hot. (Make sure crucible is not covered!!)
4. Let the crucible and contents cool completely, and reweigh promptly. To avoid any reabsorption of water from the air cover crucible when cooling!!
5. Calculate the percent water in your hydrate sample by dividing the mass of water lost by the mass the unheated sample. Report this value to your instructor, who, if the data is satisfactory, will give you the formula of your anhydrous salt. (You may need to reheat the sample to attain complete dehydration.)
6. Refer to the example calculation below to calculate the formula of the hydrate.

## EXAMPLE CALCULATIONS

1. 2.865 g of a hydrate was placed into a dessicator at 0% humidity and dehydrated completely. A constant weight was achieved since after one day the sample weighed 1.714 g and after the second day it weighed 1.713 g.

% water = [(2.865 g - 1.713 g)/2.865 g] 100% = [1.152 g/2.865 g] 100% = 40.21 %

The Instructor gave the formula $Fe(NO_3)_3 \cdot X\ H_2O$

| | |
|---|---|
| Molar Mass for the anhydrate = | 241.87 g |
| Moles of anhydrate = (1.713 g anhydrate)(1 mol/241.87 g) = | 0.00708mol |
| Moles of water = (1.152 g water)(1 mol/18.02 g) = | 0.0639 mol |
| Moles water/Moles anhydrate = 0.0639 mol water/0.00708 mol 9.03 approx. | 9 |
| The formula for the hydrate is therefore | $Fe(NO_3)_3 \cdot 9\ H_2O$. |
| Molar mass of hydrate based on formula: $Fe(NO_3)_3 \cdot 9\ H_2O$ = | 404.05 g |
| Theoretical % water = (9)(18.02 g)/404.05 g] 100% = | 40.14 % |
| % error = [(40.21% - 40.14%)/40.14%] 100% = [0.07%/40.14%] 100% = | 0.2% |

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Name______________________ day & time ___________

**1.a.** **<u>Efflorescence and Deliquescence.</u>** Compare and explain the behavior of the substances listed in the table below when they were exposed to the atmosphere. Note your observations including whether efflorescence or deliquescence was observed at the room's humidity. Your Instructor will measure the humidity. %humidity = ______ %.

**1.b.** **<u>Effect of a Drying Agent.</u>** Compare the behavior of the same substances when exposed to a drying agent. Note your observations including whether efflorescence or deliquescence was observed.

| Substance | Part 1a in atmosphere observations | Part 1 b with drying agent observations |
|---|---|---|
| $CuSO_4{\cdot}5H_2O$ | | |
| $Na_2SO_4 \cdot 10H_2O$ | | |
| $CoCl_2{\cdot}6\ H_2O$ | | |
| NaOH | | |
| $CaCl_2$ (anhydrous) | | |

2. <u>The Formula of a Hydrate</u> - **SHOW ALL CALCULATIONS and use SIGNIFICANT FIGURES**

Unknown sample ID ______

mass of crucible + lid + unknown sample ____________________ g

mass of crucible + lid ____________________ g

mass of sample ____________________ g

mass of crucible + lid + product after first heating ____________________ g

mass of crucible + lid + product after final heating ____________________ g

mass of water lost ____________________ g

mass of anhydrous salt ____________________ g

% water in hydrate ____________________ %

Instructor's approval and formula of the hydrated salt ___________

Molar Mass of anhydrous salt ____________________ g

Moles anhydrous salt in your sample ____________________ moles

Moles of water in your sample ____________________ moles

Formula of hydrate using your data ____________________

Molar Mass of hydrous salt ____________________ g

Theoretical % water in hydrate
(from Instructor's formula) ____________________ %

% error ____________________ %

**Note** any observations of the behavior of your sample, or any experimental problems.