Lab: Formula of an Unknown Hydrate

FOR THE TEACHER

Summary
In this lab, students will design a laboratory procedure in order to ultimately determine the formula of an unknown hydrated salt. Students must recognize what data points are necessary to collect during the process, as well as how to analyze the data appropriately.

Grade Level
High School

NGSS Alignment
This lab will help prepare your students to meet the performance expectations in the following standards:
- **Scientific and Engineering Practices**:
  - Planning and Carrying Out Investigations
  - Analyzing and Interpreting Data

AP Chemistry Curriculum Framework
This lab supports the following unit, topic and learning objective:
- **Unit 1: Atomic Structure and Properties**
  - **Topic 1.3**: Elemental Composition of Pure Substances
    - **SPQ-2.A**: Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.

Objectives
By the end of this lab, students should be able to
- Differentiate between a hydrated substance and an anhydrous substance.
- Calculate the percent of water (by mass) contained in a hydrated salt.
- Design appropriate laboratory procedures needed to collect the necessary data for determining the formula of a hydrate.
- Determine the formula of a hydrate from collected laboratory data.
- Evaluate experimental errors and explain their effect on the outcome of the experiment.

Chemistry Topics
This lab supports students’ understanding of
- Hydrated substances
- Percent Composition
- Law of Definite Proportions
- Experimental Design

Time
**Teacher Preparation**: 30-40 minutes
**Lesson**: 1.5-2 hours

Materials
*Students will choose from the following materials list when designing their lab, note that they do not have to use them all.*
- Hydrated copper (II) sulfate crystals
- Evaporating dish
- Crucible
- Ring stand, ring

Submitted by
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- Clay triangle
- Crucible tongs
- Beaker tongs
- Wire gauze
- 150-mL Beaker
- Bunsen Burner
- Butane Lighter
- Timer
- Triple-beam balance
- Analytical balance
- Aluminum foil
- Watch glass
- Glass stir rod

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- Always use caution around open flames. Keep flames away from flammable substances.
- Always be aware of an open flame. Do not reach over it, tie back hair, and secure loose clothing.

Teacher Notes
- The focus of this lab is not so much on the specific lab steps as it is on the scientific method, and how the students will manage the variables and controls in order to collect reliable data.
- The teacher must still include safety precautions regarding the chemicals and equipment involved, even though the procedures are created by the students. It is essential that the teacher be aware of the possible hazards inherent in a lab before asking students to create procedures for themselves.
- I use this lab in my AP chemistry class.
- Small student groups work well for this lab.
- Pre-lab questions can be assigned as homework, in advance on the lab.
- Students’ proposed procedures must be approved before experimentation; if you do not teach on a block schedule, this is best done the day before the lab. Creating their own procedures forces students to think about what data to collect.
- You will hear them asking each other questions such as, “Do we need to mass it before we add the hydrate?” Instructor guidance is essential in helping students realize that there may be variables which they have not considered, but that nevertheless need to be controlled. If certain steps are wrong, incomplete, or missing, I ask the students leading questions rather than telling them what to do: “How will you make sure it heats evenly?”, “How will you prevent water from re-entering the salt?”, “How will you know that the water has all been removed?”, and so on.
- A potential downside of this sort of modification is that students may end up performing the lab incorrectly, which can add stress when you are already on a tight schedule. For example, my students once tried to accelerate the cooling of a crucible with a damp paper towel, which resulted in the crucible cracking. They had to start over. I told them, experiments sometimes go awry; this is the way real science works. It was stressful, but it was an experience they never forgot.
- This laboratory was adapted from Mayfield Schools.

FOR THE STUDENT
Lesson

Formula of an Unknown Hydrate

Background
A compound is a pure substance—it has a fixed (constant) composition. The composition of a pure substance is the same throughout and does not vary from one sample to another. According to the law of definite proportions, a compound always contains the same elements in the same proportions, regardless of the amount of the sample, where it was found, or how it was prepared.

A hydrate is a pure substance that contains water molecules embedded in its crystal structure. Heating a hydrate "drives off" the water molecules, and the solid that remains behind is called anhydrous, meaning "without water." The chemical formula of a hydrate specifies the relative number of each kind of atom in a formula unit of the compound, as well as the number of water molecules bound to each formula unit. Calcium chloride dihydrate (CaCl₂•2H₂O), which is used as road salt, is an example of a hydrate. The "dot" in the chemical formula indicates that two water molecules (H₂O) are attached or bound to the ions in solid calcium chloride (CaCl₂). The water in calcium chloride dihydrate can be removed by heating the hydrate (Equation 1).

\[
\text{Equation 1:} \quad \text{heat} \quad \text{CaCl}_2\cdot2\text{H}_2\text{O} \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}
\]

\[
\begin{array}{ccc}
147.02 \text{ g} & \rightarrow & 110.98 \text{ g} + 36.04 \text{ g} \\
\text{dihydrate} & \text{anhydrous salt} & \text{(2 moles of water)}
\end{array}
\]

The number of water molecules in a hydrate is called the water of hydration. The water of hydration of calcium chloride dihydrate is two water molecules per every one formula unit of calcium chloride. The number of water molecules in a typical hydrate is characteristic of that particular salt and is usually a small whole number from 1 to 10. The water of hydration can be calculated by finding moles of water per mole of anhydrous salt.

**Purpose**
- To determine the percent of water (by weight) contained in a hydrated salt
- To establish the formula of a hydrated salt

**Prelab Questions**
The following data was obtained when a sample of barium chloride hydrate was analyzed:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of empty test tube</td>
<td>18.42 g</td>
</tr>
<tr>
<td>Mass of test tube and hydrate (before heating)</td>
<td>20.75 g</td>
</tr>
<tr>
<td>Mass of test tube and anhydrous salt (after heating)</td>
<td>20.41 g</td>
</tr>
</tbody>
</table>

1. Calculate the formula for the hydrate showing all work. Equations should contain units in all steps. *(Hint: find the \% of water in the hydrate, then the moles of water, then the formula. You should get a whole number ratio).*

2. Create a results table to organize the answers calculated in question 1.

**Safety**
• Always wear safety goggles when handling chemicals in the lab.
• Wash your hands thoroughly before leaving the lab.
• Follow the teacher’s instructions for cleanup of materials and disposal of chemicals.
• Always use caution around open flames. Keep flames away from flammable substances.
• Always be aware of an open flame. Do not reach over it, tie back hair, and secure loose clothing.

Procedure
1. With your lab partner(s), create a step-by-step procedure to calculate water of hydration in an unknown hydrated salt.
2. Leave space between each step so that you can add or modify steps as needed.
3. Please use a separate sheet of paper! Be as specific as possible.
4. Your procedure will be submitted to the teacher for approval prior to beginning the experiment.

Available Materials
You can choose from the following materials list for your lab, note that you do not have to use them all.
• Hydrated copper (II) sulfate crystals
• Evaporating dish
• Crucible
• Ring stand, ring
• Clay triangle
• Crucible tongs
• Beaker tongs
• Wire gauze
• 150-mL Beaker
• Bunsen Burner
• Butane Lighter
• Timer
• Triple-beam balance
• Analytical balance
• Aluminum foil
• Watch glass
• Glass stir rod

Data
Please create a data table to use for all data collection in this lab. Create this on the same piece of paper as your procedure.

Calculations
1. Calculate the % water in the hydrate.
2. Calculate the empirical formula of the compound.
3. The theoretical % of water for your hydrate is 36.1%. Calculate the percent error in your experiment by comparing the theoretical % of water with the actual percentage you obtained in your experiment.

\[
\% \text{ error} = \frac{\text{actual} - \text{theoretical}}{\text{theoretical}}
\]
4. Create a *results table* to organize the final answers from your calculations.

**Analysis**

1. If some volatile impurities are not burned off in the pre-heating step but are removed with the water, is the mass of the anhydrous salt to high or too low? Explain.

2. What happens to the sample’s reported percent water if the salt decomposes yielding a volatile product? (volatile = high vapor pressure = evaporates away easily)

3. What happens to the sample’s reported percent water if the sample oxidizes?

**Conclusion**

Be sure to explain whether each of the sources of error in questions 1-3 would result in your % water being too high or too low. Note whether any of these sources of error might explain your % error. If not, provide another viable explanation for your % error.