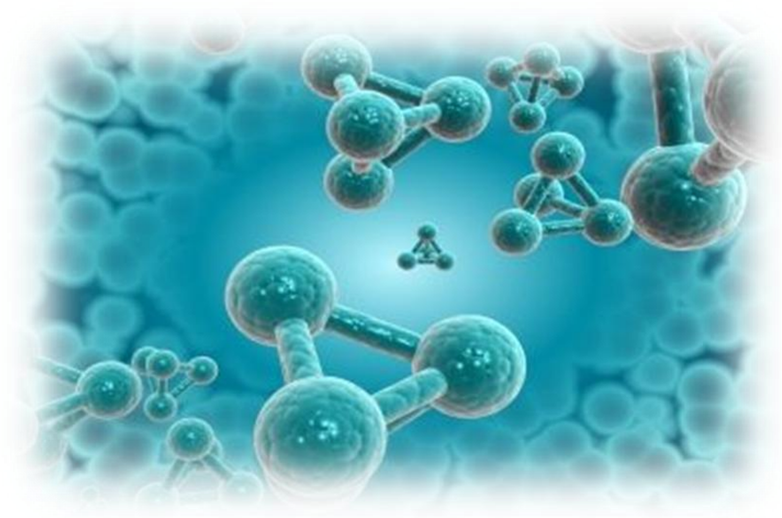
Green Chemistry Module
Level: High School Regents

Composition of a Hydrate



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Composition of a Hydrate

In this laboratory experiment, students will determine the composition of a hydrate by heating it to drive off the water of hydration. Traditionally, this lab has used copper sulfate pentahydrate as the hydrate. The use of manganese sulfate monohydrate instead of the traditional copper sulfate pentahydrate is suggested due to the decreased toxicity of the manganese sulfate compared to copper sulfate, and the fact that the manganese sulfate can be easily reused in future labs, thereby eliminating waste and reducing future chemical purchases.

It is suggested that this experiment be completed in one 60-minute (or longer) session. Students should not feel rushed so that they take the time to allow the hydrated salt to heat and cool sufficiently.

It is suggested that the teacher help the students think through the calculations by doing a warm-up exercise similar to the scenario below, rather than just giving them the formulas in the Guidance Notes.

> Help students visualize how the hydrated salt works by comparing it to a saturated sponge. (The sponge represents the salt and the water represents the waters of hydration.) Ask the students how they would find out how much water is in the sponge (squeeze the sponge and collect the water and mass it). Ask the students how they can find out what percentage of the mass of the saturated sponge is due to water (take the mass of water and divide it by the total mass and multiply by 100).

Three versions of the lab are provided:
<u>Basic Level Instruction without Formulas</u>: formulas are not included in the prelab and post lab questions
<u>Basic Level Instruction with Formulas</u>: formulas are included in the prelab and post lab questions
<u>Advanced Level Instruction</u>: For an advanced class (AP), this version assumes the student is preparing the written report independently, conducts the experiment twice and includes percent error calculations.

Composition of a Hydrate: Teacher's Guide

Intended Audience: High School Regents Chemistry Students
This experiment is aimed at students in high school learning about chemical changes and reaction types. The experiment would also be suitable for an introductory college laboratory.

Recommended Student Background: Students should be able to calculate molar masses and percentages. Students should also be familiar with writing chemical formulas and formulas for hydrated salts.

Activity Timeline:

Setup	1st Heating & Cooling	2nd Heating & Cooling	3rd Heating and Cooling (if needed)	Clean up	Total
5 min	15 min	15 min	15 min	5 min	55 min

Safety Issues: Wear approved safety goggles and suitable clothing when working with or near all chemicals in this experiment. As they leave the laboratory, students should wash hands well. In the case of skin exposure, students should wash their skin continuously for 15 minutes.
Manganese (II) sulfate monohydrate is considered an irritant, and it should be washed off the hands with a large amount of cold water (without soap). Any spills can be cleaned up with water.

Keys to Success: Students should take their time slowly drying the hydrate so as to not decompose it. Students should also be sure to allow the crucible to cool thoroughly before taking the mass after heating. Warm air rises, so heat currents could form and cause fluctuations in the mass.

Advanced Preparation:
The teacher should stage necessary equipment in a central location or at lab stations as appropriate. It may be easiest to pre-weigh enough manganese sulfate hydrate into small containers for each lab group so they can mass the 2.0 g at their lab stations. The recycling container should be centrally located to make clean-up easy and efficient.

Materials Check List:
Crucible and cover (can substitute evaporating dish)
Clay pipe triangle (can substitute wire gauze)
Tripod ***OR*** ringstand with iron ring
Bunsen burner and matches (can substitute hot plates)
Crucible tongs
microspatula
Balance (best to use a balance with 0.01g precision)
cooling pad
~ 2.0g Hydrated $MnSO_4$ ($MnSO_4 \cdot H_2O$) per student pair
A container to store and rehydrate the manganese (II) sulfate (see Recycling & Disposal below)

Measurements:
Mass of empty crucible and lid
Mass of crucible, lid and hydrated salt
Mass of crucible, lid, and anhydrous salt

Recycling and disposal:
A container to store and rehydrate the manganese (II) sulfate is required in order to reuse the material for future labs. Choose a container that is large enough to contain the material and is capable of being closed and left open to rehydrate the material.

All washings of the dirty crucible are safe to wash down the drain. The bulk of the manganese (II) sulfate is recycled by leaving the recycling container open to the air for 1-2 weeks. In humid air, the hydrate is re-formed from small samples within a few hours.

Green Chemistry: Making materials sustainably

Chemical manufacturing is as old as civilization and the discoveries of bronze and iron came to define the eras that ensued. In modern times, we take for granted a plentiful supply of metals, plastics, dyestuffs and medicines. We have come to depend on the chemical industry to provide us with all the materials we need for our "materialist" society.

But the supply of these materials is not infinite. As the human population grows, and demands an ever higher standard of living, the consumption of the Earth's materials is in danger of getting out of control. It is therefore essential that chemists become responsible stewards of the raw materials that remain. We need to develop methods for chemical processing that are both chemically and environmentally efficient, and which move us towards a sustainable society. We need new materials that can provide what we need without destroying the Earth.

Green chemistry is designed to help us meet these needs. It aims not just to treat waste, but to avoid producing waste in the first place. Products and processes should be "benign by design," but they must also be practicable.

In this lab manual, we will explore how we can this can be achieved in practice – how we can use chemistry to help solve our environmental problems. We will never be able to build a sustainable society if we don't understand the basic science of where our materials come from, and how they are produced. The goal of this manual is to provide that science, presented within the context of green chemistry.

The Twelve Principles of Green Chemistry

The basic principles of green chemistry were first laid out by two US chemists, Paul Anastas and John Warner, in their 1998 book, "Green Chemistry: Theory and Practice:"

1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.
10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.

12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

It must be recognized that these represent a target, and we will not be able to satisfy every principle immediately with every process and product. Nevertheless, if we design our chemistry with these principles in mind, we will make great strides towards achieving sustainability.

Correlation of the experiment with Green Chemistry

Green Chemistry Principles: 1. Prevent Waste
3. Design less hazardous chemical syntheses

The use of manganese sulfate monohydrate instead of the traditional copper sulfate pentahydrate is suggested due to the decreased toxicity of the manganese sulfate compared to copper sulfate, and the fact that the manganese sulfate can be easily reused in future labs, thereby eliminating waste and reducing future chemical purchases.

Curriculum alignment

Alignment to the NYS Regents Chemistry Curriculum:
III.7 The percent composition by mass of each element in a compound can be calculated mathematically. (3.3f)

This experiment correlates directly with the following section of the New York State Core Curriculum:

Standard 4: The Physical Setting.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

Performance Indicator 3.3 Apply the principle of conservation of mass to chemical reactions.

Major Understandings 3.3f The percent composition by mass of each element in a compound can be calculated mathematically.

Background and Fundamentals for Basic Level Instruction:

Many chemical compounds attract water. Some of these compounds form "hydrates" containing precise amounts of water, such as $Na_2SO_4 \bullet 12H_2O$, or $CuCl_2 \bullet 2H_2O$. These contain twelve or two moles of water per mole of Na_2SO_4 or $CuCl_2$, respectively. When heated, these compounds often lose this water to form the *anhydrous* compound, such as Na_2SO_4 or $CuCl_2$, which contain no water.

For example: $Na_2SO_4 \bullet 12H_2O \rightarrow Na_2SO_4 + 12H_2O$

In this experiment we will investigate how much water is lost from a hydrated sample of manganese (II) sulfate, $MnSO_4$. We will find this by finding the change in mass upon heating. Knowing the molar mass of $MnSO_4$ and of water, we can find the *formula* of the hydrate, which indicates its composition.

We use manganese (II) sulfate because it is relatively non-toxic, and unlike many salts it does not decompose upon strong heating. Also, it can be recycled easily, because after heating it absorbs water from the air within a few hours and re-forms the hydrate.

Guidance notes:

Mass (1) = mass of crucible and lid
Mass (2) = mass of crucible, lid, and hydrated manganese sulfate (before heating)
Mass (3) = mass of crucible, lid, and anhydrous manganese sulfate (after heating)

A	Mass of hydrated manganese(II) sulfate (before heating)	$\mathrm{A = Mass\ (2) - Mass\ (1)}$
B	Mass of anhydrous manganese(II) sulfate (after heating)	$\mathrm{B = Mass\ (3) - Mass\ (1)}$
C	Mass of water lost	$\mathrm{C = A - B}$
D	Percent water in the hydrate	$\mathrm{D = \frac{C}{A} \times 100\%}$
E	Moles of anhydrous manganese(II) sulfate ($MnSO_4$)	$\mathrm{E = \frac{B}{M_{MnSO_4}}}$ $\mathrm{(M_{MnSO_4} = molar\ mass\ of\ MnSO_4)}$
F	Moles of water lost (= water of hydration)	$\mathrm{F = \frac{C}{M_{H_2O}}}$ $\mathrm{(M_{H_2O}\ is\ the\ molar\ mass\ of\ H_2O)}$
G	Molar ratio of water to manganese(II) sulfate (F:E)	$\mathrm{G = \frac{F}{E}}$ $\mathrm{(ratio\ relative\ to\ one\ MnSO_4)}$

Answers

Pre-lab Questions

Molar mass of $MnSO_4$ = 54.9 + 32.1 + 4(16) = 151.0 g/mol
Molar mass of H_2O = 2(1) + 16 = 18.0g/mol

Questions

1. What do you know about warm air that made it important to cool the crucible before taking its mass in Step 5?

   Warm air rises; therefore if the crucible was not cooled before weighing, the rising air currents would give inaccurate mass readings.

2. Why (after cooling, step 5 in the procedure) must you weigh your sample within a few minutes? If you instead left the crucible + dried sample out open to the air, what relative mass (less, more, the same) would you expect to find by the next class period? Why?

   Since the substance is a hydrate, it is more stable when it has water in its structure. When the dried sample is left open to the air, it will absorb water from the atmosphere and its mass will increase.

3. Calculate the percent water in erbium chloride hexahydrate, $ErCl_3 \bullet 6H_2O$.

   Molar mass of $ErCl_3 \bullet 6H_2O$ = 380.8g/mol
   Mass of water in the hydrate = 6 x 18.0g/mol = 108g/mol

   % water = 108g/mol/380.8g/mol x 100 = 28.4%

4. A sample of 244 g (1.00 mol) hydrated barium chloride was heated, and it lost 36.0 g of water. What is the formula for hydrated barium chloride?

   Moles of water = 36.0g/18.0g/mol = 2 moles
   Moles of barium chloride = 1 mole (given in problem)

   Therefore, the formula for the hydrate is 2 moles of water per mole of barium chloride:
   $BaCl_2 \bullet 2H_2O$

Extension Activities

1. What is the formula for a hydrate that is 90.7% SrC_2O_4 and 9.30% H_2O?

   Assume 100 g of the substance.

   90.7g SrC_2O_4/ 175.6g/mol = 0.52 mol

   9.3g H_2O/18.0g/mol = 0.52 mol

Molar ratio of SrC_2O_4 to H_20 = 0.52:0.52 = 1:1

Therefore, the formula for the hydrate is: SrC_2O_4●H_2O

2. What is the formula for a hydrate that is 433.5 grams of Mo_2S_5 and 66.5 grams of H_2O?

433.5g/352.3g/mol = 1.23 moles Mo_2S_5

66,5g/18.0g/mol = 3.69 moles H_2O

Molar ratio of Mo_2S_5 to H_20 = 1.23:3.69 = 1:3

Therefore, the formula for the hydrate is: Mo_2S_5●$3H_2O$

Background and Fundamentals for Advanced Level Instruction:

Water of Hydration is included as one of the 22 recommended labs for AP Chemistry. The concepts reinforced through this lab are often the basis for AP test questions; therefore a thorough understanding of the concepts and lab procedures are necessary for AP Chemistry.

The background information is the same as for the Basic level of instruction. Students carry out the same procedures as in the basic level of instruction. It is suggested that AP students complete the procedure twice (or three times if the first two trials are not reasonably close) and average the results for greater accuracy. Students include percent error calculations comparing their experimental results to the theoretical value.

Use pages 11, 12 and 20 for the Advanced version of the lab. The Advanced level report is written independently by the student following teacher expectations, and includes all information requested in the lab report.

Answers:

Pre-Lab:

1. Define "hygroscopic".
   Hygroscopic - Absorbing or attracting water
   Anhydrous – without water
2. Are hydrates classified as compounds or mixtures? Explain.
   Hydrates are compounds containing specific amounts of water trapped in their crystal structures; therefore they are pure substances. Each hydrate contains a very specific number of moles of water trapped within its crystal structure.
3. Calculate the gram formula mass of each of the following:
   a. $CuCl_2 \bullet 2H_2O$
      63.5 + 2(35.5) + 2(18.0) = 170.5g/mol
   b. $CuCl_2$
      63.5 + 2(35.5) = 134.5g/mol
   c. $CuSO_4 \bullet 5H_2O$
      63.5 + 32.1 + 4(16.0) + 5(18.0) = 249.6g/mol
   d. $CuSO_4$
      63.5 + 32.1 + 4(16.0) = 159.6g/mol
4. Calculate the percent water in erbium chloride hexahydrate, $ErCl_3 \bullet 6H_2O$.
   Molar mass of $ErCl_3 \bullet 6H_2O$ = 380.8g/mol
   Mass of water in the hydrate = 6 x 18.0g/mol = 108g/mol
   % water = 108g/mol/380.8g/mol x 100 = 28.4%

Report:

1. What is the formula for the manganese sulfate hydrate?
   $MnSO4 \bullet H_2O$
2. What is the theoretical percent water for the hydrate?
   18/169 x 100 = 10.65%
3. What was your experimental percent water for the hydrate?
   Answers will vary
4. What was your percent error?
   Answers will vary. Difference between experimental % water and theoretical % water/Theoretical % water x 100

5. List two sources of error that could have affected the mass of the hydrate. Describe how each of those errors may have impacted the results.
   Answers will vary but should include sources such as not heating the sample long enough to drive off all the water resulting in lower values for the water mass; spattering during heating allowing some of the hydrate to leave the crucible thereby reducing the mass of the hydrate itself but appearing to increase the mass of water lost as a result; accidentally transferring some of the hydrate out of the crucible with the spatula after stirring thereby increasing the mass of water lost; not heating the crucible to dryness before beginning the experiment, thereby artificially increasing the amount of water lost; not cooling the crucible sufficiently before massing, thereby appearing to increase the amount of water lost (through “lift” due to warm air currents making the actual mass appear less than it really is)

Composition of a Hydrate

Laboratory Experiment # _________

Name ___________________________________ Date ________________________________

Partner ___________________________________

Introduction

Many chemical compounds attract water. Some of these compounds form "hydrates" containing precise amounts of water, such as $Na_2SO_4 \bullet 12H_2O$, or $CuCl_2 \bullet 2H_2O$. These contain twelve or two moles of water per mole of Na_2SO_4 or $CuCl_2$, respectively. When heated, these compounds often lose this water to form the *anhydrous* compound, such as Na_2SO_4 or $CuCl_2$, which contain no water.

For example: $Na_2SO_4 \bullet 12H_2O \rightarrow Na_2SO_4 + 12H_2O$

In this experiment we will investigate how much water is lost from a hydrated sample of manganese (II) sulfate, $MnSO_4$. We will find this by finding the change in mass upon heating. Knowing the molar mass of $MnSO_4$ and of water, we can find the *formula* of the hydrate, which indicates its composition.

What is Green Chemistry?

The goal of green chemistry is to design chemicals and processes that reduce or eliminate negative environmental impacts. This includes products and processes that use or generate less hazardous substances, reduced waste products, less or non-toxic components, and using substances more efficiently. Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations.

Green chemistry provides a number of benefits, including:

- reduced waste, eliminating costly end-of-the-pipe treatments
- safer products
- reduced use of energy and resources
- improved competitiveness of chemical manufacturers and their customers.

There are twelve principles that green chemistry relies on that were first laid out by two US chemists, Paul Anastas and John Warner, in their 1998 book, "Green Chemistry: Theory and Practice”:

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the starting materials. There should be few, if any, wasted atoms.

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Why is this experiment green?

Traditionally, this lab is performed with copper sulfate pentahydrate, a chemical used in pesticides. It is irritating to eyes and skin and may cause eczema.

We use manganese (II) sulfate instead because it is relatively non-toxic, and unlike many salts it does not decompose upon strong heating. Also, it can be recycled easily, because after heating it absorbs water from the air within a few hours and re-forms the hydrate.

Safety

- Wear approved safety goggles and suitable clothing through the duration of the lab.
- Wash hands well at end of lab. If you get any manganese (II) sulfate monohydrate on your skin, wash your skin for 15 minutes without soap.
- Long hair must be tied back when using open flame.
- Clean up all spills with water.

Materials

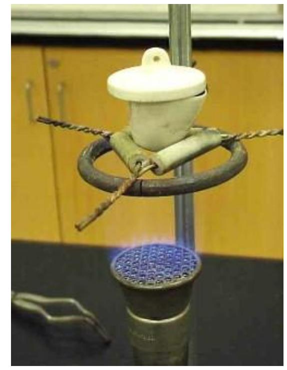
crucible and cover (can substitute evaporating dish)
clay pipe triangle (can substitute wire gauze)
tripod or ringstand with iron ring
Bunsen burner and matches (can substitute hot plates)
crucible tongs
microspatula
balance
cooling pad
~ 2.0g Hydrated $MnSO_4$ ($MnSO_4 \cdot H_2O$)

Procedure:

1. Find the mass of a clean, dry crucible (with lid) to the nearest 0.01 g. Record in the data table (1).

2. Add approximately 2 g hydrated manganese (II) sulfate to the crucible (with lid), and note the total mass (crucible + lid + contents) to the nearest 0.01 g. Record the data in the table (2).

3. Set up a pipe-clay triangle on a ring stand or tripod as shown, and place the crucible inside it. Tilt the crucible lid slightly so that water vapor can escape.



4. Using a Bunsen burner, heat the crucible and contents for five minutes.

5. Allow the crucible to cool completely (this takes around ten minutes), then find the total mass of the crucible + lid + dried contents. Be sure to use the crucible tongs to handle the crucible and cover. (What do you know about warm air and why would we want the crucible to cool before we take its mass?) Record the mass in the data table (3).

6. Use a microspatula to gently stir the solid to release any trapped water molecules, being careful not to remove any of the solid from the crucible. Reheat the crucible as before, for three minutes.

7. Once again, allow the crucible to cool then take the total mass. If this differs significantly (> 0.02 g) from the dried mass found before, reheat for another three minutes and recheck the mass after recooling. Repeat this step as many times as needed to get to a constant mass. Record the final mass in the data table (4).

8. Return the dried manganese (II) hydrate to the recycling container provided by the instructor.

9. Clean the crucible, crucible cover and microspatula by rinsing well with water. Put away the other equipment, and wipe down your lab station with a wet cloth or sponge.

Recycling and disposal: All washings of the dirty crucible are safe to wash down the drain. The bulk of the manganese (II) sulfate is recycled by leaving the recycling container open to the air for 1-2 weeks. In humid air, the hydrate is re-formed from small samples within a few hours.

Experiment

Pre-lab:

Calculate the molar mass for anhydrous manganese (II) sulfate ($MnSO_4$) and for water (H_2O). Show your calculations:

$MnSO_4$	**H_2O**

Data: List all the masses in grams, to the nearest 0.01 g (or better if a more precise scale is available).

1	Mass of empty crucible + lid	
2	Mass of crucible + lid + hydrated manganese(II) sulfate (**before heating**)	
3	Mass of crucible + lid + hydrated manganese(II) sulfate (**after first heating**)	
4	Mass of crucible + lid + hydrated manganese(II) sulfate (**after final heating**)	
5	Observations during the experiment:	

Experiment

Pre-lab:

Calculate the molar mass for anhydrous manganese (II) sulfate ($MnSO_4$) and for water (H_2O). Show your calculations:

$MnSO_4$

Element	# of atoms	At. Mass	Total Mass
		TOTAL	

H_2O

Element	# of atoms	At. Mass	Total Mass
		TOTAL	

Data: List all the masses in grams, to the nearest 0.01 g (or better if a more precise scale is available).

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3	Mass of crucible + lid + hydrated manganese(II) sulfate (**after first heating**)	
4	Mass of crucible + lid + hydrated manganese(II) sulfate (**after final heating**)	
5	Observations during the experiment:	

Calculations: For the purposes of the calculation, assume all of the water is driven off, and anhydrous manganese (II) sulfate is formed. Do not just show your answers, but also show how you set up the calculation. You have all the information you need to solve the calculations in the data table above and the molar masses of water and manganese (II) sulfate calculated in the pre-lab.

A. Mass of hydrated manganese(II) sulfate (before heating) =
(Mass of crucible + lid + hydrated manganese(II) sulfate (**before heating**) - Mass of empty crucible + lid)

B. Mass of anhydrous manganese(II) sulfate (after final heating) =
(Mass of crucible + lid + hydrated manganese(II) sulfate (**after heating**) - Mass of empty crucible + lid)

C. Mass of water lost =
(Mass of $MnSO_4$ before heating (A) – Mass of $MnSO_4$ after heating (B))

D. Percent water in the hydrate =
(Mass of water lost (C)/Mass of hydrated $MnSO_4$ (A) * 100)

E. Moles of anhydrous manganese(II) sulfate ($MnSO_4$) =
(Mass of anhydrous $MnSO_4$ (B)/molar mass of $MnSO_4$ (from pre-lab)

F. Moles of water lost (= water of hydration) =
(Mass of water (C)/molar mass of water (from pre-lab)

G. Molar ratio of water to manganese(II) sulfate (F:E) (round to the nearest whole number) =
(Moles of water (F)/moles of anhydrous $MnSO_4$ (E))

Conclusions:

Write the formula of the hydrated manganese sulfate:_______________________________________

Questions:

1. What do you know about warm air that made it important to cool the crucible before taking its mass in Step 5?

2. Why (after cooling, step 5 in the procedure) must you weigh your sample within a few minutes? If you instead left the crucible + dried sample out open to the air, what relative mass (less, more, the same) would you expect to find by the next class period? Why?

3. Calculate the percent water in erbium chloride hexahydrate, $ErCl_3 \bullet 6H_2O$.

4. A sample of 244 g (1.00 mol) hydrated barium chloride was heated, and it lost 36.0 g of water. What is the formula for hydrated barium chloride?

Extension Activities

1. What is the formula for a hydrate that is 90.7% SrC_2O_4 and 9.30% H_2O?

2. What is the formula for a hydrate that is 433.5 grams of Mo_2S_5 and 66.5 grams of H_2O?

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2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary

chemicals. If these chemicals are necessary, use innocuous chemicals.

9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.
10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

Why is this experiment green?

Traditionally, this lab is performed with copper sulfate pentahydrate, a chemical used in pesticides. It is irritating to eyes and skin and may cause eczema.

We use manganese (II) sulfate instead because it is relatively non-toxic, and unlike many salts it does not decompose upon strong heating. Also, it can be recycled easily, because after heating it absorbs water from the air within a few hours and re-forms the hydrate.

Safety

- Wear approved safety goggles and suitable clothing through the duration of the lab.
- Wash hands well at end of lab. If you get any manganese (II) sulfate monohydrate on your skin, wash your skin for 15 minutes without soap.
- Long hair must be tied back when using open flame.
- Clean up all spills with water.

Materials

crucible and cover (can substitute evaporating dish)
clay pipe triangle (can substitute wire gauze)
tripod or ringstand with iron ring
Bunsen burner and matches (can substitute hot plates)
crucible tongs
microspatula
balance
cooling pad
~ 2.0g Hydrated $MnSO_4$ ($MnSO_4 \cdot H_2O$)

Pre-Lab:

1. Define "hygroscopic" and "anhydrous".
2. Are hydrates classified as compounds or mixtures? Explain.
3. Calculate the gram formula mass of each of the following:
    a. $CuCl_2 \bullet 2H_2O$
    b. $CuCl_2$
    c. $CuSO_4 \bullet 5H_2O$
    d. $CuSO_4$
4. Calculate the percent water in erbium chloride hexahydrate, $ErCl_3 \bullet 6H_2O$.

Procedure:

1. Heat and cool a crucible and lid, then find the mass of the clean, dry crucible (with lid) to the nearest 0.001 g.
2. Mass approximately 2 g hydrated manganese (II) sulfate in the crucible (with lid) to the nearest 0.001 g.
3. Place the crucible on pipe-clay triangle on a ring stand or tripod Tilt the crucible lid slightly so that water vapor can escape.
4. Using a Bunsen burner, heat the crucible and contents for five minutes. You should periodically stir and separate the hydrate crystals using a microspatula, being careful to keep all crystals in the crucible.
5. Allow the crucible to cool completely, and find the total mass of the crucible + lid + dried contents to the nearest 0.001g
6. Reheat the crucible as before, for three minutes. Remass. If the mass is the same as the previous mass, it is completely dehydrated. If it is not the same, continue the heating/cooling cycle until two successive readings are the same.
7. Return the dried manganese (II) hydrate to the recycling container provided by the instructor.
8. Repeat the entire procedure as a second trial and average the two results before completing calculations. If the two trials are not reasonably close, complete a third trial.

Recycling and disposal: All washings of the dirty crucible are safe to wash down the drain. The bulk of the manganese (II) sulfate is recycled by leaving the recycling container open to the air for 1-2 weeks. In humid air, the hydrate is re-formed from small samples within a few hours.

Report:

The lab report should consist of an introduction, answers to pre-lab questions, brief description of procedures, data table including all relevant data, calculations, and answers to the following questions:

1. What is the formula for the manganese sulfate hydrate?
2. What is the theoretical percent water for the hydrate?
3. What was your experimental percent water for the hydrate?
4. What was your percent error?
5. List two sources of error that could have affected the mass of the hydrate. Describe how each of those errors may have impacted the results.