How Much Water Is in That Solid?

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16 minutes to next solid line

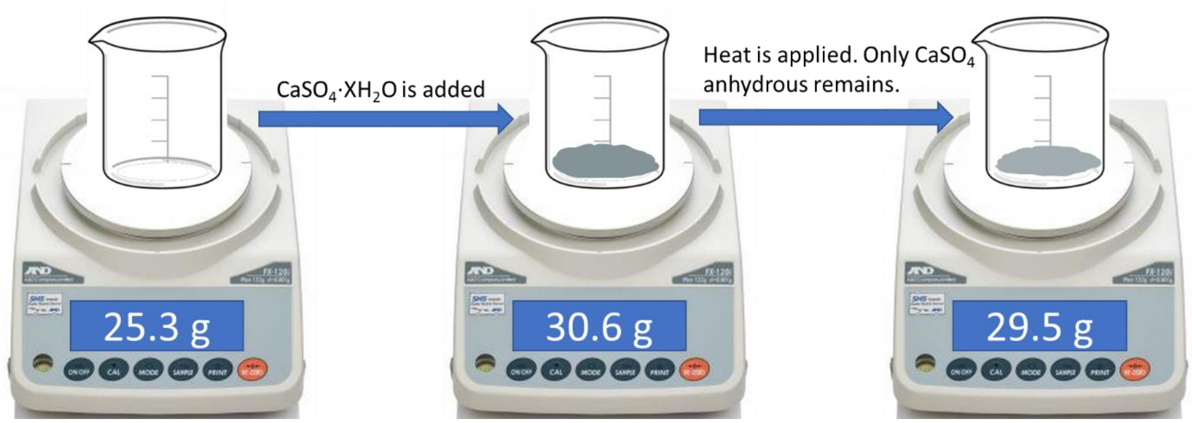
Before beginning, start pre-heating the oven to 400°F (204°C).

Information: Hydrates form when water molecules are bound within the crystal structure of a solid compound. A common example of a hydrate is $CuSO_4 \cdot 5H_2O$ (5 moles of water are bound to every 1 mole of $CuSO_4$).

$$CuSO_4 \cdot 5H_2O(s) \xrightarrow{\Delta} CuSO_4(s) + 5H_2O(l)$$

The name of this hydrate is copper(II) sulfate pentahydrate. The water molecules can often be removed from the solid structure by applying heat. This process is called dehydration, and the compound remaining is called an anhydrous salt.

Model 1: Determining the stoichiometry of a hydrate, $CaSO_4 \cdot XH_2O$.



Key Questions:

1. What is the total mass of the $CaSO_4 \cdot XH_2O$ added to the beaker? Do not forget that the mass on the balance also includes the beaker. 5.3 g

2. Heating the $CaSO_4 \cdot XH_2O$ drives off the water. Determine the mass of the water in the original hydrate. 1.1 g

3. What is the mass of the anhydrous $CaSO_4$ remaining in the beaker? 4.2 g

4. Convert the mass of anhydrous $CaSO_4$ to moles. Show your work and use dimensional analysis. Periodic table is at the end of the activity.

$$\frac{4.2g}{40.078\frac{g}{mol}+32.06\frac{g}{mol}+4\cdot 15.999\frac{g}{mol}}=0.031mol$$

5. Convert the mass of the water that was driven off when heated to moles. Show your work and use dimensional analysis.

$$\frac{1.1g}{2\cdot 1.008\frac{g}{mol}+15.999\frac{g}{mol}}=0.061mol$$

6. The value of "X" in $CaSO_4\cdot XH_2O$ can now be determined by dividing the moles of H_2O determined previously by the moles of anhydrous $CaSO_4$. Determine the value of "X" and write the correct formula for the hydrate.

$$X=\frac{0.061}{0.031}=2 \qquad CaSO_4\cdot 2H_2O$$

Exercises:

7. According to the balanced chemical equation below, KCl can be produced from $KClO_3$. Follow the steps below to determine the grams of KCl that can be produced from 1.778 g of $KClO_3$. Note: The triangle above the arrow indicates heat is applied.

$$2KClO_3(s) \xrightarrow{\Delta} 2KCl(s) + 3O_2(g)$$

a. Convert the grams of $KClO_3$ to moles. Show your work and use dimensional analysis.

$$\frac{1.778g}{39.098\frac{g}{mol}+35.45\frac{g}{mol}+3\cdot 15.999\frac{g}{mol}}=0.01451mol$$

b. Using the coefficients from the balanced chemical equation, calculate the moles of KCl produced from the moles of $KClO_3$ determined above. Show your work and use dimensional analysis.

$$0.01451mol, KClO_3\cdot\frac{2mol, KCl}{2mol, KClO_3}=0.01451mol, KCl$$

c. Now, convert the moles of KCl determined above to grams of KCl. Show your work and use dimensional analysis.

$$0.01451mol\cdot\left(39.098\frac{g}{mol}+35.45\frac{g}{mol}\right)=1.082g$$

Entire class discussion:

Method development:

Items needed for *each* member of the group: Epsom salt (provided by the balances), table salt (provided by the balances), $NaHCO_3$ (provided by the balances), cupcake liners (3 for each group member), and scoopulas (3 for each group member),.

8. You are going to determine the value of "X" in Epson salt ($MgSO_4 \cdot XH_2O$) and table salt ($NaCl \cdot XH_2O$). You will also decompose $NaHCO_3$ by applying heat. Describe a method to perform these reactions above with the provided items.

Get the mass of each of them before applying heat and getting rid of the water then get the mass again after to find out the mass of the first compound and the mass of the water with it. You can then calculate the moles of each and divide the waters moles by the compounds to find X

9. Examine the Epsom salt and the table salt. You can handle them since they are nontoxic. Based on appearance and feel what would you say about the amount of water contained in each salt?
    a. Epsom salt

    It's much more clear so I'd think it has more water to make it clear compared to table salt

    b. Table salt

    It's not clear so i think it has less water compared to epsom salt

10. Describe the appearance of the baking soda.

    Its a white powder

Individual data collection (each person in the group will acquire their own data):

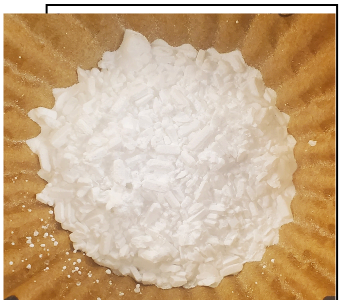
11. For $MgSO_4 \cdot XH_2O$ and $NaCl \cdot XH_2O$, the water is removed by applying heat to produce the anhydrous salts. For the baking soda, applying heat causes a reaction and new substances to form. The below steps will assist you in performing the experiments. Place masses in the table below.
    a. Acquire three mini cupcake liners. Label the inside edge of each cupcake liner with a pen: one with "$MgSO_4 \cdot XH_2O$"; one with "$NaCl \cdot XH_2O$"; and the last one with "$NaHCO_3$". Label the inside edge of each cupcake liner with your initials as well. Acquire the mass of each cupcake liner without the compound (place masses in table below).
    b. Measure out 3.5 to 4.0 grams of each compound in the appropriately labeled cupcake liner and acquire the mass (place masses in the table below). Break up clumps if necessary. Use a clean scoopula to do this.
    c. With your cell phone, take a clear picture of each substance *before heating*. The pictures need to clearly show the appearance of each substance.



d. Place your cupcake liners in a provided aluminum tray. The teacher or lab assistant will place the tray in the oven 415°F (213°C) for 20 minutes. You will be notified when the 20 minutes have expired. There will be some waiting time while heat is applied to the compounds. During this time, you can work on the problems in "Application of Principles".
e. Allow the compounds to cool for 3 minutes and acquire the mass (place in table below).

	Mass of cupcake liner	**Mass of cupcake liner and compound before heating**	**Mass of cupcake liner and anhydrous compound after heating**
Epsom salt	0.155 g	3.735 g	2.219 g
Table salt	0.163 g	3.889 g	3.909 g
Baking soda	0.159 g	3.705 g	2.437 g

f. Take a clear picture of each substance *after* heating. The pictures need to clearly show the appearance of each substance.



g. How does the appearance of each compound change by heating?
   i. Epsom salt

   It's not clear anymore and is white now and its all clumped together in one chunk

   ii. Table salt

   It looks the same as it did before

iii. $NaHCO_3$

It looks the same as it did before

12. From the data in the previous data, calculate the following for the two salts.

	Mass of anhydrous salt	Mass of water in salt
Epsom salt	2.064 g	1.516 g
Table salt	3.746 g	- 0.02

13. To derive the "X" value for each salt, you need to convert grams to moles. Do these conversions and show your work by using dimensional analysis.

	Moles of anhydrous salt	Moles of water in salt
Epsom salt	0.0171 mol	0.08415 mol
Table salt	0.06410 mol	0.00111 mol

$$\frac{2.064g}{24.305\,\frac{g}{mol}+32.06\,\frac{g}{mol}+4\cdot 15.999\,\frac{g}{mol}}=0.01715mol,\,MgSO_4$$

$$\frac{1.516g}{2\cdot 1.008\,\frac{g}{mol}+15.999\,\frac{g}{mol}}=0.08415mol,\,H_2O$$

$$\frac{3.746g}{22.99\,\frac{g}{mol}+35.45\,\frac{g}{mol}}=0.06410mol,\,NaCl$$

$$-\frac{0.02}{2\cdot 1.008\,\frac{g}{mol}+15.999\,\frac{g}{mol}}=-0.001110mol,\,H_2O$$

14. Determine the value of "X" for $MgSO_4\cdot XH_2O$ and $NaCl\cdot XH_2O$. This was done in Model 1 for $CaSO_4\cdot H_2O$. Round to the tenths place.

X = 4.9 ($MgSO_4\cdot XH_2O$)

X = 0.0 ($NaCl\cdot XH_2O$)

$$\frac{0.08415mol,\,H_2O}{0.01715mol,\,MgSO_4}=4.9$$

$$\frac{-0.001110mol,\,H_2O}{0.06410mol,\,NaCl}=0.0$$

<u>Compilation of group data and group analysis</u>:

15. In the table below, input the "X" value for each group member (including your own) and then calculate an average "X" for your group.

	"X" value for $MgSO_4$	"X" value for NaCl
Group member	4.9	0.0
Group member	4.0	0.0
Group member	4.7	0.0
Group member	2.5	0.5
AVERAGE VALUE	4.0	0.1

16. Are the "X" values determined by your group members precise? Explain how you made this determination. If the "X" values aren't precise, suggest a reason.
    - Epsom salt Precise? No

    Could've used slightly different values of atomic mass of stuff depending on the table we each used or spilling some/measurement error

    - Table salt: Precise? Yes

17. The actual hydrate for magnesium sulfate is reported to be $MgSO_4 \cdot 7H_2O$. Suggest a reason why your group's value is lower than this.

    We spilled a little

18. What type of hydrate is table salt?

    Anhydrous

19. Based on the AVERAGE VALUE for "X" write down the formula for each hydrate.
    $MgSO_4 \cdot XH_2O$ $MgSO_4 \cdot 4H_2O$
    $NaCl \cdot XH_2O$ $NaCl \cdot 0.1H_2O$

Class data: In the class data sheet (link in Canvas), input the average values for the salts.

Information: When baking soda ($NaHCO_3$) is heated, it reacts releasing a gas (or gases). The other product is a solid; sodium carbonate (Na_2CO_3), sodium oxide (Na_2O), or sodium hydroxide ($NaOH$). Equations for all these reactions are written below. *Only one of these reactions occurs*. The correct reaction will be determined by performing stoichiometric calculations with the data acquired by heating the baking soda.

$$2NaHCO_3(s) \xrightarrow{\Delta} H_2O(g) + CO_2(g) + Na_2CO_3(s) \quad \underline{\text{Equation 1}}$$

$$2NaHCO_3(s) \xrightarrow{\Delta} H_2O(g) + 2CO_2(g) + Na_2O(s) \quad \underline{\text{Equation 2}}$$

$$NaHCO_3(s) \xrightarrow{\Delta} CO_2(g) + NaOH(s) \quad \underline{\text{Equation 3}}$$

20. For each reaction, what is the *solid* product that forms (place in table below)? From the balanced chemical equation, determine the mole ratio of the baking soda ($NaHCO_3$) to that solid product. Note: The ratio of moles is indicated by the coefficients.

	Solid product	**Mole ratio of $NaHCO_3$ to solid product (X $NaHCO_3$: Y product)**
Equation 1	Na_2CO_3	$2:1$
Equation 2	Na_2O	$2:1$
Equation 3	$NaOH$	$1:1$

21. Let's do a practice problem. Suppose that an amount of 1.50 grams of $NaHCO_3$ is heated.
    a. Determine the moles of $NaHCO_3$. Show your work. Periodic table is at the end of the activity.

$$\frac{1.50g}{22.990\frac{g}{mol}+1.008\frac{g}{mol}+12.011\frac{g}{mol}+3\cdot 15.999\frac{g}{mol}} = 0.0179mol$$

    b. For each reaction specified above (Equations 1-3), use the mole ratio to determine the moles of solid product that would form. Show your work and use dimensional analysis.

	Moles of solid product formed
Equation 1	0.00895 mol
Equation 2	0.00895 mol
Equation 3	0.0179 mol

Equation 1:

$$0.0179mol, NaHCO_3 \cdot \frac{1mol, Na_2CO_3}{2mol, NaHCO_3} = 0.00895mol, Na_2CO_3$$

Equation 2:

$$0.0179mol, NaHCO_3 \cdot \frac{1mol, Na_2O}{2mol, NaHCO_3} = 0.00895mol, Na_2O$$

Equation 3:

$$0.0179mol, NaHCO_3 \cdot \frac{1mol, NaOH}{1mol, NaHCO_3} = 0.0179mol, NaOH$$

c. From the moles of the solid product determined above, calculate the grams of each solid product. Show your work and use dimensional analysis.

	Grams of solid product formed
Equation 1	0.949 g
Equation 2	0.555 g
Equation 3	0.716 g

Equation 1:

$$0.00895 mol, Na_2CO_3 \cdot \left(2 \cdot 22.99 \frac{g}{mol} + 12.011 \frac{g}{mol} + 3 \cdot 15.999 \frac{g}{mol}\right) = 0.949 g$$

Equation 2:

$$0.00895 mol, Na_2O \cdot \left(2 \cdot 22.99 \frac{g}{mol} + 15.999 \frac{g}{mol}\right) = 0.555 g$$

Equation 3:

$$0.0179 mol, NaOH \cdot \left(22.99 \frac{g}{mol} + 15.999 \frac{g}{mol} + 1.008 \frac{g}{mol}\right) = 0.716 g$$

Comparing the amount of actual solid products from the reaction with the values in the table will indicate which reaction (Equation 1, 2 or 3) occurred.

Ask the teacher or lab assistant to check your work for the calculations above before proceeding.

Individual data collection (each person in the group will acquire their own data):

22. From the actual mass data above for $NaHCO_3$ calculate the following.

	Mass of $NaHCO_3$ before heating	Mass of new product after heating
Baking soda	3.546 g	2.278 g

23. Calculate the amount of solid in grams that can form for each Equation starting with the amount of $NaHCO_3$ before heating in the table above. Show your work and use dimensional analysis. Periodic table is at the end of the activity.

	Expected amount of solid in grams
Equation 1	2.237 g
Equation 2	1.308 g
Equation 3	1.688 g

$2NaHCO_3(s) \xrightarrow{\Delta} H_2O(g) + CO_2(g) + Na_2CO_3(s)$ Equation 1

$2NaHCO_3(s) \xrightarrow{\Delta} H_2O(g) + 2CO_2(g) + Na_2O(s)$ Equation 2

$$MM, Na_2CO_3 = 105.988 \frac{g}{mol}$$

$$MM, Na_2O = 61.979 \frac{g}{mol}$$

$$MM, NaOH = 39.997 \frac{g}{mol}$$

2NaHCO3(s) $\xrightarrow{\Delta}$ $H_2O(g) + 2CO_2(g) + 2NaOH(s)$ <u>Equation 3</u>

$$\frac{3.546g}{84.006\,\frac{g}{mol}} = 0.04221mol, NaHCO_3$$

Equation 1:

$$0.04221mol, NaHCO_3 \cdot \frac{1mol, Na_2CO_3}{2mol, NaHCO_3} = 0.02111mol, Na_2CO_3 \cdot \left(105.988\,\frac{g}{mol}\right) = 2.237g, Na_2CO_3$$

Equation 2:

$$0.04221mol, NaHCO_3 \cdot \frac{1mol, Na_2O}{2mol, NaHCO_3} = 0.02111mol, Na_2O \cdot \left(61.979\,\frac{g}{mol}\right) = 1.308g, Na_2O$$

Equation 3:

$$0.04221mol, NaHCO_3 \cdot \frac{2mol, NaOH}{2mol, NaHCO_3} = 0.04221mol, NaOH \cdot \left(39.997\,\frac{g}{mol}\right) = 1.688g, Na_2O$$

24. Compare the expected masses of solids products calculated from each equation with the actual amount of substance in the beaker after heating. Based on this comparison, what is most likely the solid product in the beaker after heating?

Na_2CO_3

<u>Compilation of group data and group analysis:</u>

25. In the table below, indicate which equation was selected by each group member (including your own selection).

	Equation 1, 2 or 3?
Group member	1
Group member	1
Group member	1
Group member	1

26. Did every group member select the same equation/reaction for the decomposition of baking powder? yes

27. If there were disagreement for the selection among your group members, suggest a reason for this.

no disagreement

Class data: In the class data sheet (link in Canvas), indicate the selected chemical equation (Equation 1, Equation 2, or Equation 3) for your group.

Make sure all items are clean and return them to the drawer or bench. Finish cleaning any glassware used by rinsing with distilled water. Before you leave, ask the teacher or lab assistant to examine your data and laboratory space. Note: Your data must be entered into the spreadsheet before you leave.

Application of principles (to be completed individually):

28. Balance the chemical equation shown below:

2 $Al_2O_3(l)$ $\rightarrow$ 4 Al(s) + 3 $O_2(g)$

29. Based on the balanced chemical equation, how many grams of Al(s) will form when 18.55 g of Al_2O_3 decomposes? You must show your work by writing below or inserting a picture of your work. Use dimensional analysis.

$$\frac{18.55g}{2 \cdot 26.982\,\frac{g}{mol} + 3 \cdot 15.999\,\frac{g}{mol}} = 0.1819mol, Al_2O_3$$

$$0.3638mol \cdot 26.982\,\frac{g}{mol} = 9.816g$$

$$0.1819mol, Al_2O_3 \cdot \frac{4mol, Al}{2mol, Al_2O_3} = 0.3638mol, Al$$

30. When 6.62 g of the $CoCl_2{\cdot}XH_2O$ hydrate is heated the water is removed. The mass of the anhydrous salt is 3.61 g. Determine the value of X and write the correct formula. You must show your work by writing below or inserting a picture of your work. Use dimensional analysis.

$$\frac{3.61g}{58.933\,\frac{g}{mol} + 2 \cdot 35.45\,\frac{g}{mol}} = 0.0278mol, CoCl_2$$

$$X = \frac{0.167mol, H_2O}{0.0278mol, CoCl_2} = 6$$

$$\frac{6.62 - 3.61}{2 \cdot 1.008\,\frac{g}{mol} + 15.999\,\frac{g}{mol}} = 0.167mol, H_2O$$

$$CoCl_2 \cdot 6H_2O$$

31. You are now going to compare your individual values with the average values of the class in the *Class Data Sheet*. Make sure the *Class Data Sheet* is complete before doing this. You will have to wait until the end of the lab period. Fill in the following table below.

	Your individual value	**Average value of class**
“X” value for $MgSO_4{\cdot}XH_2O$	4.9	4.8
“X” value for $NaCl{\cdot}XH_2O$	0.0	0.1

The agreement between a measured value and an accepted value can be analyzed by performing a percent error calculation (equation given below). For this calculation, the measured value is your individual value, and the accepted value is the class average (in Google Sheet).

$$Percent\ Error = \frac{(measured\ value - accepted\ value)}{accepted\ value} \times 100.0\%$$

a. Calculate a percent error for your magnesium sulfate hydrate.

	Percent error
"X" value for $MgSO_4 \cdot XH_2O$	2.1%

$$\frac{4.9 - 4.8}{4.8} \cdot 100\% = 2.1\%$$

b. If your percent error is greater than 15% (or less than -15%), suggest at least one reason for your individual value being significantly different than the accepted value.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.008																	2 **He** 4.0026
3 **Li** 6.94	4 **Be** 9.0122											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.630	33 **As** 74.922	34 **Se** 78.97	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.95	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57-71 *	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89-103 #	104 **Rf** (265)	105 **Db** (268)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289)	115 **Mc** (289)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

* Lanthanide series	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
# Actinide series	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)