Determine the formula of a hydrate

Problem #1: A 15.67 g sample of a hydrate of magnesium carbonate was heated, without decomposing the carbonate, to drive off the water. The mass was reduced to 7.58 g. What is the formula of the hydrate?

Problem #2: A hydrate of Na_2CO_3 has a mass of 4.31 g before heating. After heating, the mass of the anhydrous compound is found to be 3.22 g. Determine the formula of the hydrate and then write out the name of the hydrate.

Problem #3: When you react 3.9267 grams of $Na_2CO_3 \cdot nH_2O$ with excess HCl(aq), 0.6039 grams of a gas is given off. What is the number of water molecules bonded to Na_2CO_3 (value of n)?

Problem #4: If 1.951 g $BaCl_2 \cdot nH_2O$ yields 1.864 g of anhydrous $BaSO_4$ after treatment with sulfuric acid, calculate n.

Problem #5: Given that the molar mass of $Na_2SO_4 \cdot nH_2O$ is 322.1 g/mol, calculate the value of n.

Problem #6: Anhydrous lithium perchlorate (4.78 g) was dissolved in water and re-crystalized. Care was taken to isolate all the lithium perchlorate as its hydrate. The mass of the hydrated salt obtained was 7.21 g. What hydrate is it?

Problem #7: A substance was found to have the following percentages by mass: 23% zinc; 11% sulfur; 22% oxygen; 44% water. What is the empirical formula?

Problem #8: A 5.00 g sample of hydrated barium chloride, $BaCl_2 \cdot nH_2O$, is heated to drive off the water. After heating, 4.26 g of anhydrous barium chloride, $BaCl_2$, remains. What is the value of n in the hydrate's formula?

Problem #9: A 1.98 g sample of a cobalt(II) chloride hydrate is heated over a burner. When cooled, the mass of the remaining dehydrated compound is found to be 1.55 g. What is the formula for the original hydrate? How can you make sure that all of the water of hydration has been removed?

Problem #10: A solution was made by dissolving 52.0 g of hydrated sodium carbonate in water and making it up to 5.00 dm^3 of solution. The concentration of the solution was determined to be 0.0366 M. Determine the formula of hydrated sodium carbonate.

Bonus problem: A hydrate of magnesium chloride is present and the following data is collected:

mass of crucible = 22.130 grams
mass of crucible + hydrate = 25.290 grams
mass of crucible and contents after heating = 23.491 grams

What is the complete formula of this hydrate?

Answer key

Problem #1: A 15.67 g sample of a hydrate of magnesium carbonate was heated, without decomposing the carbonate, to drive off the water. The mass was reduced to 7.58 g. What is the formula of the hydrate?

Solution:

1) Determine mass of water driven off:
   15.67 minus 7.58 = 8.09 g of water
2) Determine moles of $MgCO_3$ and water:
   $MgCO_3$ --> 7.58 g / 84.313 g/mol = 0.0899 mol
   H_2O --> 8.09 g / 18.015 g/mol = 0.449 mol
3) Find a whole number molar ratio:
   $MgCO_3$ --> 0.0899 mol / 0.0899 mol = 1
   H_2O --> 0.449 mol / 0.0899 mol = 5
   $MgCO_3 \cdot 5H_2O$

Problem #2: A hydrate of Na_2CO_3 has a mass of 4.31 g before heating. After heating, the mass of the anhydrous compound is found to be 3.22 g. Determine the formula of the hydrate and then write out the name of the hydrate.

Solution:

1) Determine mass of water driven off:
   4.31 minus 3.22 = 1.09 g of water
2) Determine moles of Na_2CO_3 and water:
   Na_2CO_3 --> 3.22 g / 105.988 g/mol = 0.0304 mol
   H_2O --> 1.09 g / 18.015 g/mol = 0.0605 mol
3) Find a whole number molar ratio:
   Na_2CO_3 --> 0.0304 mol / 0.0304 mol = 1
   H_2O --> 0.0605 mol / 0.0304 mol = 2
   $Na_2CO_3 \cdot 2H_2O$
   sodium carbonate dihydrate

Comment: sodium carbonate forms three hydrates and the above is not one of them. This is a problem probably crafted so that you cannot look up possible answers via the InterTubez®. Just sayin'.

Problem #3: When you react 3.9267 grams of $Na_2CO_3 \cdot nH_2O$ with excess HCl(aq), 0.6039 grams of a gas is given off. What is the number of water molecules bonded to Na_2CO_3 (value of n)?

Solution:

1) Some preliminary comments:
   Ignore the water of hydration for a moment.
   $Na_2CO_3 + 2HCl \text{ ---> } CO_2 + 2NaCl + H_2O$
   The key is that there is a 1:1 molar ratio between Na_2CO_3 and CO_2
2) Determine moles of CO_2:
   0.6039 g / 44.009 g/mol = 0.013722 mol of CO_2
3) Use the 1:1 molar ratio referenced above:
   This means that the HCl reacted with 0.013722 mole of sodium carbonate.
4) How many grams of Na_2CO_3 is that?
   0.013722 mol times 105.988 g/mol = 1.4544 g
5) Determine grams, then moles of water
   3.9267 g minus 1.4544 g = 2.4723 g of water
   2.4723 g / 18.015 g/mol = 0.13724 mol of water
6) For every one Na_2CO_3, how many waters are there?
   0.13724 mol / 0.013722 mol = 10
   $Na_2CO_3 \cdot 10H_2O$

Comment: this is one of the three sodium carbonate hydrates that exists.

Problem #4: If 1.951 g $BaCl_2 \cdot nH_2O$ yields 1.864 g of anhydrous $BaSO_4$ after treatment with sulfuric acid, calculate n.

Solution:

1) Calculate mass of Ba in $BaSO_4$:
   1.864 g times (137.33 g/mol / 233.39 g/mol) = 1.0968 g
2) Calculate mass of anhydrous $BaCl_2$ that contains 1.0968 g of Ba:
   1.0968 g is to 137.33 g/mol as x is to 208.236 g/mol
   x = 1.663 g
3) Calculate mass of water in original sample:
   1.951 g minus 1.663 g = 0.288 g
4) Calculate moles of anhydrous $BaCl_2$ and water:
   1.663 g / 208.236 g/mol = 0.0080
   0.288 g / 18.015 g/mol = 0.0160
5) Express the above ratio in small whole numbers with $BaCl_2$ set to a value of one:
   1 : 2
   $BaCl_2 \cdot 2H_2O$

Problem #5: Given that the molar mass of $Na_2SO_4 \cdot nH_2O$ is 322.1 g/mol, calculate the value of n.
Solution:
1) The molar mass of anhydrous Na_2SO_4 is:
142.041 g/mol
2) The mass of water in one mole of the hydrate is:
322.1 g - 142.041 g = 180.059 g
3) Determine moles of water:
180.059 g / 18.0 g/mol = 10 mol
4) Write the formula:
$Na_2SO_4 \cdot 10H_2O$

Problem #6: Anhydrous lithium perchlorate (4.78 g) was dissolved in water and re-crystalized. Care was taken to isolate all the lithium perchlorate as its hydrate. The mass of the hydrated salt obtained was 7.21 g. What hydrate is it?
Solution:
1) The amount of water in the hydrate is:
7.21 g minus 4.78 g = 2.43 g
2) The moles of anhydrous $LiClO_4$ and water are:
$LiClO_4$ --> 4.78 g / 106.39 g/mol = 0.044929 mol
H_2O --> 2.43 g / 18.015 g/mol = 0.13489 mol
3) Determine whole number ratio:
$LiClO_4$ --> 0.044929 mol / 0.044929 mol = 1
H_2O --> 0.13489 mol / 0.044929 mol = 3
$LiClO_4 \cdot 3H_2O$

Problem #7: A substance was found to have the following percentages by mass: 23% zinc; 11% sulfur; 22% oxygen; 44% water. What is the empirical formula?
Solution:
1) Assume 100 g of the compound is present, then find the moles of each:
Zn --> 23 /65.4 = 0.352
S --> 11/32 = 0.344
O --> 22/16 = 1.375
H_2O --> 44/ 18 = 2.44
2) Divide the smallest number into the others. The answers will not be exact but enough to tell the formula:
Zn --> 0.352 / 0.344 = 3
S --> 0.344 / 0.344 = 1
O --> 1.375 / 0.344 = 3
H_2O --> 2.44 / 0.344 = 7
The formula is $ZnSO_4 \cdot 7H_2O$

Problem #8: A 5.00 g sample of hydrated barium chloride, $BaCl_2 \cdot nH_2O$, is heated to drive off the water. After heating, 4.26 g of anhydrous barium chloride, $BaCl_2$, remains. What is the value of n in the hydrate's formula?
Solution:
1) Calculate moles of anhydrous barium chloride:
4.26 g / 208.236 g/mol = 0.020458 mol
2) Calculate moles of water:
5.00 minus 4.26 = 0.74 g
0.74 g / 18.015 g/mol = 0.041077 mol
3) Determine whole number ratio:
0.041077 / 0.020458 = 2
4) Formula is:
$BaCl_2 \cdot 2H_2O$

Problem #9: A 1.98 g sample of a cobalt(II) chloride hydrate is heated over a burner. When cooled, the mass of the remaining dehydrated compound is found to be 1.55 g. What is the formula for the original hydrate? How can you make sure that all of the water of hydration has been removed?
Solution:
1) determine mass of water driven off:
1.98 g minus 1.55 g = 0.43 g
2) Determine moles of anhydrous $CoCl_2$ and H_2O:
$CoCl_2$ --> 1.55 g / 129.839 g/mol = 0.01194 mol
H_2O --> 0.43 g / 18.015 g/mol = 0.0239 mol
3) Look for lowest whole-number ratio:
$CoCl_2$ --> 0.01194 mol / 0.01194 mol = 1
H_2O --> 0.0239 mol / 0.01194 mol = 2
4) Formula is:
$CoCl_2 \cdot 2H_2O$
5) How can you make sure that all of the water of hydration has been removed?
After weighing the anhydrous $CoCl_2$, you would continue to heat it. Then, you would weigh it again. If the two weights are in agreement, then you are done heating. If the two weights disagree, you continue heating and weighing until you gets weights that agree. In some cases, where an extra amount of care must be taken, you would want three straight weighings that were in agreement.
Also, weighs being in agreement does not mean that they are exactly the same. The standards for being in agreement might vary from one instructor to the next, so make sure to consult with your lab teacher on this point.

Problem #10: A solution was made by dissolving 52.0 g of hydrated sodium carbonate in water and making it up to 5.00 dm^3 of solution. The concentration of the solution was determined to be 0.0366 M. Determine the formula of hydrated sodium carbonate.

Solution:

1) moles of hydrated sodium carbonate in 5.00 liters:
   0.0366 mol/L times 5.00 L = 0.183 mol
2) molecular weight of hydrated sodium carbonate:
   52.0 g / 0.183 mol = 284.153 g/mol
3) mass of water in one mole of hydrate:
   284.153 - 105.988 = 178.165 g
   (105.988 is molar mass of anhydrous sodium carbonate)
4) moles of water in one mole of hydrate:
   178.165 g / 18.018 g/mol = 9.9 mol
5) formula of hydrated sodium carbonate:
   $Na_2CO_3 \cdot 10H_2O$

Bonus Problem: A hydrate of magnesium chloride is present and the following data is collected:

mass of crucible = 22.130 grams
mass of crucible + hydrate = 25.290 grams
mass of crucible and contents after heating = 23.491 grams

What is the complete formula of this hydrate?

1) mass of hydrate:
   25.290 g - 22.130 g = 3.160 g
2) mass of anhydrate:
   23.491 g - 22.130 g = 1.181 g
3) water lost:
   3.160 g - 1.181 g = 1.979 g
4) moles $MgCl_2$:
   1.181 g / 95.211 g/mol = 1.24 mol
5) moles water lost:
   1.979 g / 18.015 g/mol = 0.109853 mol
6) molar ratio of $MgCl_2$ to water is:
   1 : 11.3
   Within fairly reasonable experimental error, the formula of the hydrate is:
   $MgCl_2 \cdot 12H_2O$