ChemQuest 31

Using Moles with Formulas

Name: ____________________________

Date: _______________

Hour: _____

Information: Percent Composition

Sometimes it is needful to know the composition of a compound. For example, 39.3% of the mass of sodium chloride is due to sodium. The other 60.7% of the mass is from chlorine. So, in a 100 g sample of sodium chloride, there are 39.3 g of sodium and 60.7 g of chlorine. This type of data is known as percent composition. The percent composition tells you the percentage by mass of an element in a compound. There is a convenient formula for finding the percent composition of an element in a compound:

(obtained from periodic table)

$$\text{percent composition of element "X"} = \frac{\text{mass of x in one mole of the compound}}{\text{mass of one mole of the compound}} \bullet 100$$

(obtained from periodic table)

Let us look at how the percent composition of calcium (Ca) in calcium chloride ($CaCl_2$) was determined.

$$\text{percent composition of Ca} = \frac{\text{mass of Ca in one mole of } CaCl_2}{\text{mass of one mole of } CaCl_2} \bullet 100$$

from periodic table for calcium

$$\text{percent composition of Ca} = \frac{40.1\text{ g}}{111.1\text{ g}} \bullet 100 = 36.1\%$$

from periodic table for calcium + 2 chlorines;
40.1 + 2(35.5) = 111.1

As another example, consider calculating the percent composition of nitrogen in Ca_3N_2:

From periodic table for 2 nitrogen atoms: 2(14.0)=28.0

$$\text{percent composition of N} = \frac{28.0\text{ g}}{148.3\text{ g}} \bullet 100 = 18.9\%$$

from periodic table for 3 calcium + 2 nitrogen atoms
3(40.1) + 2(14.0) = 148.3

Critical Thinking Questions

1. Verify that in C_4H_{10} the percent composition of carbon is approximately 82.6%.

$$\frac{4(12.0)}{[4(12.0)+10(1.01)]} \bullet 100 = 82.6\%$$

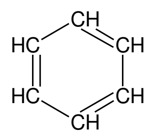
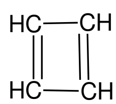
Note: 12.0 and 1.01 are the molar masses for carbon and hydrogen on the periodic table.

2. Calculate the percent composition of sodium in Na_2S.

$$\frac{2(23.0)}{[2(23.0)+(32.1)]} \bullet 100 = 58.9\%$$

Information: Formulas and Percent Composition

Table 1: Percent composition and formulas of some compounds.

Name	Structural Formula	Molecular Formula	% Comp. of H	% Comp. of C
Hexene	$H_2C{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_3$	C_6H_{12}	14.4	85.6
Propene	$H_2C{=}CH{-}CH_3$	C_3H_6	14.4	85.6
Benzene		C_6H_6	7.8	92.2
Cyclobutadiene		C_4H_4	7.8	92.2
1,5-hexadi-yne	$HC{\equiv}C{-}CH_2{-}CH_2{-}C{\equiv}CH$	C_6H_6	7.8	92.2

Critical Thinking Questions

3. Verify that the percent composition of C and H given for hexene in Table 1 are correct.
   For carbon: $$\frac{6(12.0)}{[6(12.0)+12(1.01)]} \bullet 100 = 85.6\%$$
   For hydrogen: 100-85.6 = 14.4%

4. Fill in the blanks in Table 1 by determining the percent composition and the molecular formulas of each compound.
   See table above.

5. Can you determine a compound's structural formula if you are given the molecular formula? Explain.
   No, for example, hexene and cyclohexane each have the same molecular formula, but different structural formulas.

6. What is true about the percent composition of two different compounds that each have the same molecular formula?
   If two compounds have the same molecular formula they will have the same percent composition as well.

7. Can you determine a molecule's molecular formula solely from the percent composition? Explain.
   No. As can be seen in the Table 1, compounds with different molecular formulas may still have the same percent composition.

8. Using only the information in Table 1 (no calculators or periodic tables), predict the percent composition of each of the following compounds:

Molecular Formula	% Composition of H	% Composition of C
C_8H_8	7.8	92.2
$C_{10}H_{20}$	14.4	85.6

   Note: any compound with a 1:1 ratio of carbon to hydrogen will have 92.2% carbon and 7.8% hydrogen. Any compound with a 1:2 ratio will have 85.6% carbon and 14.4% hydrogen.

Information: Empirical Formulas

An empirical formula is a formula that describes the lowest whole-number ratio of elements in a compound. An example of an empirical formula is CH, which is the empirical formula for benzene whose molecular formula was given in Table 1.

Critical Thinking Questions

9. What is the empirical formula of a compound whose percent composition is 92.2% carbon and 7.8% hydrogen? (See question 8 and Table 1.)
   The empirical formula must be CH as demonstrated in question 8 and Table 1.

10. If you know the percent composition of each atom in a molecule, can you determine the empirical formula for the compound?
    Yes you can, although right now you may not be sure exactly how to do this.

Information: Calculating the Empirical Formula

When you know the percent composition of each element in a compound, you can calculate the empirical formula of that compound. The following example will illustrate how to do this.

Example 1: A certain compound is 30.4% nitrogen and 69.6% oxygen by mass. What is the empirical formula of the compound?

Step #1: Divide each percentage by the molar mass from the periodic table:

For Nitrogen: $\frac{30.4}{14.0} = 2.17$ For Oxygen: $\frac{69.6}{16.0} = 4.35$

Step #2: Find the ratio of nitrogen to oxygen. To do this, find the smallest number obtained in step #1. In this example, the smallest answer is 2.17. Now divide each of your answers to step #1 by this smallest number. In this example, you should divide each answer by 2.17:

For Nitrogen: $\frac{2.17}{2.17} = 1.00$ For Oxygen: $\frac{4.35}{2.17} = 2.00$

Step #3: Write the formula. The answers from step #2 are the subscripts in the formula! The formula therefore is NO_2.

If in step #2 you get something like Nitrogen = 1.00 and Oxygen = 2.50 then the formula you write in step #3 would be $NO_{2.5}$. This doesn't make sense because all subscripts must be whole numbers. You would need to double *each* subscript. The formula would be $N_{1x2}O_{2.5x2}$ = $\mathbf{N_2O_5}$.

Critical Thinking Questions

11. Find the empirical formula for a compound that contains 82.4% nitrogen and 17.6% hydrogen.

5.89 is smaller than 17.4

For nitrogen: $\frac{82.4}{14.0} = 5.89$ For hydrogen: $\frac{17.6}{1.01} = 17.4$

Divide by the smallest: 5.89/5.89 = 1 17.4/5.89 = 2.95 → 3.0

The formula therefore is N_1H_3, or just $\mathbf{NH_3}$.

Information: Calculating the Molecular Formula from the Empirical Formula

Remember that the empirical formula is just a simplification of the molecular formula. For example, consider the empirical formula NO. There are several possible molecular formulas including: N_2O_2, N_3O_3, N_4O_4, etc. Which one is it? Notice that the possible formula N_2O_2 is made up of two of the empirical formulas, NO. Similarly, N_3O_3 is made up of three of the empirical formulas, NO. How do we know which empirical formula is correct? We need is the molar mass of the molecular formula.

Critical Thinking Questions

12. The empirical formula for a certain compound is NO. The molar mass of the compound is 60.0 g/mol.
    a) What is the molar mass of the empirical formula? (Use the periodic table.)
       14.0 + 16.0 = 30.0
    b) Divide the molar mass of the compound (given in the question) by the molar mass of the empirical formula found in part a.
       60.0/30.0 = 2.0
    c) Your answer to part b tells you how many empirical formulas are in the molecular formula. You now should be able to write the correct molecular formula, which is N_2O_2. Verify that the correct molecular formula is N_2O_2.
       We found in part b that there are 2 empirical formulas in the molecular formula, therefore the molecular formula must be $N_{1x2}O_{1x2}$ = N_2O_2.

13. a) What is the empirical formula of a compound whose percent composition by mass is 85.7% carbon and 14.3% hydrogen?

    For carbon: $\frac{85.7}{12.0} = 7.14$ For hydrogen: $\frac{14.3}{1.01} = 14.2$

    Divide by smallest: 7.14/7.14 = 1 14.2/7.14 = 1.99 → 2

    The empirical formula is therefore: $\mathbf{CH_2}$

    b) If the compound has a molar mass of 56 g/mol, what is the molecular formula?
       Molar mass of empirical formula from part a = 12.0 + 2(1.01) = 14.02
       56/14.02 = 3.99 → 4; Molecular formula = $C_{1x4}H_{2x4}$ = $\mathbf{C_4H_8}$