Percent Composition of Compounds

The percent by mass of each element in a compound is called the **percent composition** of a compound. The percent by mass of any element in a compound can be found by dividing the mass of the element by the mass of the compound and multiplying by 100.

$$\frac{mass\ of\ element}{mass\ of\ compound} \times 100 = percent\ by\ mass$$

If you already know the chemical formula for a compound, you can calculate the percent composition by using the molar masses of the elements and the compound.

It is important to note that the percent composition of a compound is always the same, no matter the size of the sample. If we assume a sample size of one mole, it will greatly simplify our calculations.

Example 1
Determine the percent composition of water (H_2O).

Example 2
Sodium hydrogen carbonate, also called baking soda, is an active ingredient in some antacids. Determine the percent composition of baking soda ($NaHCO_3$).

Empirical Formula

Suppose that the identities of the elements in a sample of an unknown compound have been determined, and the compound's percent composition is known. This data can be used to determine the formula for the compound.

The **empirical formula** for a compound is the formula with the smallest whole-number ratio of the elements. The empirical formula may or may not be the same as the actual molecular formula.

Compound	Molecular Formula	Empirical Formula
Water	H_2O	H_2O
Hydrogen Peroxide	H_2O_2	HO

The following steps will allow you to determine the empirical formula of a compound (given the percent composition):

1. Assume a sample size of 100 g.

2. Convert the percentage of each element to a mass.

3. Convert each mass into moles.

4. If the number of moles are not whole numbers, then divide each by the smallest number of moles.

5. Multiply by some value x in order to make all whole number of moles.

Example 3
An unknown compound has a percent composition of 40.05% sulfur and 59.95% oxygen. Determine the empirical formula of this compound.

Example 4

Methyl acetate is a solvent commonly used in some paints. Determine the empirical formula for methyl acetate, given its percent composition: 48.64% carbon, 8.16% hydrogen, and 43.20% oxygen.

Molecular Formula

It is possible for two or more substances with distinctly different properties to have the same percent composition and the same empirical formula. For example, both benzene and acetylene have an empirical formula of CH.

The simplest ratio does not always indicate the actual number of moles in the compound. To identify an unknown compound, a chemist must go one step further and determine the **molecular formula**, which specifies the actual number of atoms of each element in one molecule of formula unit of the substance.

To determine the molecular formula for a compound:

1. Obtain the empirical formula.
2. Calculate the mass corresponding to the empirical formula.
3. Calculate the ratio:

$$\frac{molar\ mass}{empirical\ formula\ mass}$$

4. Multiply the subscripts of the empirical formula by the ratio in Step 3.

For example, benzene has the empirical formula CH.

$$molar\ mass\ of\ CH = 13.02\ g/mol$$

The experimentally determined molar mass of benzene is $78.12\ g/mol$.

$$\frac{78.12\ g/mol}{13.02\ g/mol} = 6$$

Dividing the actual molar mass by the mass of the empirical formula indicates that the molar mass of benzene is six times the mass of the empirical formula. Thus, the molecular formula for benzene should be six times the empirical formula.

$$C_6H_6$$

Example 5
Acetylene has an empirical formula of CH. The molar mass of acetylene has been experimentally determined to be $26.04\ g/mol$. Determine the molecular formula for acetylene.

Worksheet

1. Determine the percent by mass of each element in calcium chloride.

2. Calculate the percent composition of sodium sulfate.

3. Which has the larger percent by mass of sulfur, H_2SO_3 or $H_2S_2O_8$?

4. What is the percent composition of phosphoric acid (H_3PO_4)?

5. A blue solid is found to contain 36.84% nitrogen and 63.16% oxygen. What is the empirical formula for this solid?

6. Determine the empirical formula for a compound that contains 35.98% aluminum and 64.02% sulfur.

7. Propane is a hydrocarbon, a compound composed only of carbon and hydrogen. It is 81.82% carbon and 18.18% hydrogen. What is the empirical formula?

8. The chemical analysis of aspirin indicates that the molecule is 60.00% carbon, 4.44% hydrogen, and 35.56% oxygen. Determine the empirical formula for aspirin.

9. What is the empirical formula for a compound that contains 10.89% magnesium, 31.77% chlorine, and 57.34% oxygen?

10. Analysis of a chemical used in photographic developing fluid indicates a chemical composition of 65.45% carbon, 5.45% hydrogen, and 29.09% oxygen. The molar mass is found to be 110.0 g/mol. Determine the molecular formula.

11. A compound was found to contain 49.98 g of carbon and 10.47 g of hydrogen. The molar mass of the compound is 58.12 g/mol. Determine the molecular formula.

12. A colorless liquid composed of 46.68% nitrogen and 53.32% oxygen has a molar mass of 60.01 g/mol. What is the molecular formula?