

Molecular formulas For many compounds, the empirical formula is not the true formula. For example, you found the empirical formula for acetic acid in Practice Problem 26 to be CH_2O .

Chemists have learned, though, that acetic acid is a molecule with the formula $\text{C}_2\text{H}_4\text{O}_2$, which is the molecular formula for acetic acid. A **molecular formula** tells the exact number of atoms of each element in a molecule or formula unit of a compound. Notice that the molecular formula for acetic acid ($\text{C}_2\text{H}_4\text{O}_2$) has exactly twice as many atoms of each element as the empirical formula (CH_2O). The molecular formula for a compound is always a whole-number multiple of the empirical formula.

In order to determine the molecular formula for an unknown compound, you must know the molar mass of the compound in addition to its empirical formula. Then you can compare the molar mass of the compound with the molar mass represented by the empirical formula as shown in the following example problem.

Example Problem 10-9

Determining a Molecular Formula

Maleic acid is a compound that is widely used in the plastics and textiles industries. The composition of maleic acid is 41.39% carbon, 3.47% hydrogen, and 55.14% oxygen. Its molar mass is 116.1 g/mol. Calculate the molecular formula for maleic acid.

Start by determining the empirical formula for the compound as shown in Example Problem 11-8.

$$\text{moles of C (in 100 g)} = 41.39 \text{ g} \cancel{\text{C}} \times \frac{1 \text{ mol C}}{12.011 \text{ g} \cancel{\text{C}}} = 3.446 \text{ mol C}$$

$$\text{moles of H (in 100 g)} = 3.47 \text{ g} \cancel{\text{H}} \times \frac{1 \text{ mol H}}{1.008 \text{ g} \cancel{\text{H}}} = 3.442 \text{ mol H}$$

$$\text{moles of O (in 100 g)} = 55.14 \text{ g} \cancel{\text{O}} \times \frac{1 \text{ mol O}}{15.999 \text{ g} \cancel{\text{O}}} = 3.446 \text{ mol O}$$

The numbers of moles of C, H, and O are nearly equal, so it is not necessary to divide through by the smallest value. You can see by inspection that the smallest whole-number ratio is 1C : 1H : 1O, and the empirical formula is CHO.

Next, calculate the molar mass represented by the formula CHO. Here, the molar mass is the sum of the masses of one mole of each element.

$$\text{molar mass CHO} = 12.011 \text{ g} + 1.008 \text{ g} + 15.999 \text{ g}$$

$$\text{molar mass CHO} = 29.018 \text{ g/mol}$$

As stated in the problem, the molar mass of maleic acid is known to be 116.1 g/mol. To determine the molecular formula for maleic acid, calculate the whole number multiple, n , to apply to its empirical formula.

$$n = \frac{116.1 \text{ g/mol maleic acid}}{29.018 \text{ g/mol CHO}} = 4.001$$

This calculation shows that the molar mass of maleic acid is four times the molar mass of its empirical formula CHO. Therefore, the molecular formula must have four times as many atoms of each element as the empirical formula. Thus, the molecular formula is $(\text{CHO})_4 = \text{C}_4\text{H}_4\text{O}_4$. A check of the molecular formula for maleic acid in a reference book will confirm this result.

Practice Problems

30. Ricinine is one of the poisonous compounds found in the castor plant. The composition of ricinine is 58.54% carbon, 4.91% hydrogen, 17.06% nitrogen, and 19.49% oxygen. Ricinine's molar mass is 164.16 g/mol. Determine its molecular formula.
31. The compound borazine consists of 40.29% boron, 7.51% hydrogen, and 52.20% nitrogen, and its molar mass is 80.50 g/mol. Calculate the molecular formula for borazine.
32. The composition of silver oxalate is 71.02% silver, 7.91% carbon, and 21.07% oxygen. If the molar mass of silver oxalate is 303.8 g/mol, what is its molecular formula?
33. A compound of phosphorus and sulfur contains 27.87% phosphorus and 72.13% sulfur. The molar mass of the compound is 222.3 g/mol. Calculate its molecular formula.
34. Triethylenemelamine is used in the plastics industry and as an anticancer drug. Its analysis is 52.93% carbon, 5.92% hydrogen, and 41.15% nitrogen. The molar mass of triethylenemelamine is 204.2 g/mol. Determine its molecular formula.