Pearson

4.9: Formula Mass and the Mole Concept for Compounds

We have now discussed how to name compounds and write formulas for them. It is also useful to be able to quantify the mass of a compound. In Chapter 1, we defined the average mass of an atom of an element as its *atomic mass*. Similarly, we now define the average mass of a molecule (or a formula unit) of a compound as its **formula mass**. (The terms *molecular mass* or *molecular weight* are synonymous with formula mass and are also common.) For any compound, the formula mass is the sum of the atomic masses of all the atoms in its chemical formula.

$$\text{formula mass} = \left(\begin{array}{c}\text{number of atoms}\\\text{of 1st element in}\\\text{chemical formula}\end{array} \times \begin{array}{c}\text{atomic mass}\\\text{of}\\\text{1st element}\end{array}\right) + \left(\begin{array}{c}\text{number of atoms}\\\text{of 2nd element in}\\\text{chemical formula}\end{array} \times \begin{array}{c}\text{atomic mass}\\\text{of}\\\text{2nd element}\end{array}\right)$$

For example, the formula mass of carbon dioxide, CO_2, is:

Multiply by 2 because formula has 2 oxygen atoms.

$$\begin{aligned}\text{formula mass} &= 12.01\ \text{amu} + 2(16.00\ \text{amu})\\ &= 44.01\ \text{amu}\end{aligned}$$

and that of sodium oxide, Na_2O, is:

Multiply by 2 because formula has 2 sodium atoms.

$$\begin{aligned}\text{formula mass} &= 2(22.99\ \text{amu}) + 16.00\ \text{amu}\\ &= 61.98\ \text{amu}\end{aligned}$$

Example 4.9 Calculating Formula Mass

Calculate the formula mass of glucose, $C_6H_{12}O_6$.

SOLUTION

To find the formula mass, add the atomic masses of each atom in the chemical formula.

$$\begin{aligned}\text{formula mass} &= 6 \times (\text{atomic mass C}) + 12 \times (\text{atomic mass H}) + 6 \times (\text{atomic mass O})\\ &= 6(12.01\ \text{amu}) + 12(1.008\ \text{amu}) + 6(16.00\ \text{amu})\\ &= 180.16\ \text{amu}\end{aligned}$$

FOR PRACTICE 4.9 Calculate the formula mass of calcium nitrate.

Molar Mass of a Compound

Recall from Section 1.10 that an element's molar mass—the mass in grams of one mole of its atoms—is numerically equivalent to its atomic mass. We use the molar mass in combination with Avogadro's number to determine the number of atoms in a given mass of the element. The same concept applies to compounds. The *molar mass of a compound*—the mass in grams of 1 mol of its molecules or formula units—is numerically equivalent to its formula mass. For example, we just calculated the formula mass of CO_2 to be 44.01 amu. The molar mass is, therefore:

> Remember, ionic compounds do not contain individual molecules. In casual language, the smallest electrically neutral collection of ions is sometimes called a molecule but is more correctly called a formula unit.

$$CO_2 \text{ molar mass} = 44.01 \text{ g/mol}$$

Using Molar Mass to Count Molecules by Weighing

The molar mass of CO_2 is a conversion factor between mass (in grams) and amount (in moles) of CO_2. Suppose we want to find the number of CO_2 molecules in a sample of dry ice (solid CO_2) with a mass of 10.8 g. This calculation is analogous to Example 1.7, where we found the number of atoms in a sample of copper of a given mass. We begin with the mass of 10.8 g and use the molar mass to convert to the amount in moles. Then we use Avogadro's number to convert to number of molecules. The conceptual plan shows the progression.

Conceptual Plan

$$\boxed{\text{g } CO_2} \xrightarrow{\frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2}} \boxed{\text{mol } CO_2} \xrightarrow{\frac{6.022 \times 10^{23}\ CO_2 \text{ molecules}}{1 \text{ mol } CO_2}} \boxed{CO_2 \text{ molecules}}$$

To solve the problem, we follow the conceptual plan, beginning with 10.8 grams CO_2, converting to moles, and then to molecules.

Solution

$$10.8\ \cancel{\text{g } CO_2} \times \frac{1\ \cancel{\text{mol } CO_2}}{44.01\ \cancel{\text{g } CO_2}} \times \frac{6.022 \times 10^{23}\ CO_2 \text{ molecules}}{1\ \cancel{\text{mol } CO_2}} = 1.48 \times 10^{23}\ CO_2 \text{ molecules}$$

Example 4.10 The Mole Concept—Converting between Mass and Number of Molecules

An aspirin tablet contains 325 mg of acetylsalicylic acid ($C_9H_8O_4$). How many acetylsalicylic acid molecules does it contain?

SORT You are given the mass of acetylsalicylic acid and asked to find the number of molecules.

GIVEN: 325 mg $C_9H_8O_4$

FIND: number of $C_9H_8O_4$ molecules

STRATEGIZE First convert to grams and then to moles (using the molar mass of the compound) and then to number of molecules (using Avogadro's number). You need both the molar mass of acetylsalicylic acid and Avogadro's number as conversion factors. You also need the conversion factor between g and mg.

CONCEPTUAL PLAN

$$\text{mg } C_9H_8O_4 \xrightarrow[\text{1 mg}]{10^{-3}\text{ g}} \text{g } C_9H_8O_4 \xrightarrow[\text{180.15 g } C_9H_8O_4]{\text{1 mol } C_9H_8O_4} \text{mol } C_9H_8O_4 \xrightarrow[\text{1 mol } C_9H_8O_4]{6.022\times10^{23}\ C_9H_8O_4 \text{ molecules}} \text{number of } C_9H_8O_4 \text{ molecules}$$

RELATIONSHIPS USED

$$\begin{aligned} C_9H_8O_4 \text{ molar mass} &= 9(12.01) + 8(1.008) + 4(16.00) \\ &= 180.15 \text{ g/mol} \end{aligned}$$

$6.022 \times 10^{23} = 1 \text{ mol}$

$1 \text{ mg} = 10^{-3} \text{ g}$

SOLVE Follow the conceptual plan to solve the problem.

SOLUTION

$$325 \ \cancel{\text{mg}}\ \cancel{C_9H_8O_4} \times \frac{10^{-3}\ \cancel{\text{g}}}{1\ \cancel{\text{mg}}} \times \frac{1 \text{ mol } \cancel{C_9H_8O_4}}{180.15\ \cancel{\text{g}}\ \cancel{C_9H_8O_4}} \times \frac{6.022 \times 10^{23}\ C_9H_8O_4 \text{ molecules}}{1 \text{ mol } \cancel{C_9H_8O_4}}$$

$$= 1.09 \times 10^{21}\ C_9H_8O_4 \text{ molecules}$$

CHECK The units of the answer, $C_9H_8O_4$ molecules, are correct. The magnitude is smaller than Avogadro's number, as expected, since you have less than one molar mass of acetylsalicylic acid.

FOR PRACTICE 4.10 Find the number of ibuprofen molecules in a tablet containing 200.0 mg of ibuprofen ($C_{13}H_{18}O_2$).

FOR MORE PRACTICE 4.10 What is the mass of a sample of water containing 3.55×10^{22} H_2O molecules?

Interactive Worked Example 4.10 **The Mole Concept—Converting between Mass and Number of Molecules**

Conceptual Connection 4.8 **Molecular Models and the Size of Molecules**

Interactive