Formula Mass

A formula mass is the sum of the atomic masses of all the atoms represented in the chemical formula of a substance. (The term "formula mass" can be used for both ionic and molecular compounds.) Formula masses are similar to the atomic masses from which they are calculated; both are relative masses based on the relative mass scaled to carbon-12. Formula masses are calculated by simply adding the atomic masses of the elements in the compound—count each atomic mass as many times as the symbol for the elements occurs in the chemical formula.

For example: What is the formula mass for **(a)** tin (II) fluoride, SnF_2, and **(b)** urea, $(NH_2)_2CO$?

(a) One formula unit of SnF_2 contains 1 Sn atom and 2 F atoms

$$1 \text{ atom Sn} \times \left(\frac{118.71 \text{ amu}}{1 \text{ atom Sn}}\right) = 118.71 \text{ amu}$$

$$2 \text{ atom F} \times \left(\frac{19.00 \text{ amu}}{1 \text{ atom F}}\right) = \underline{38.00 \text{ amu}}$$

$$\text{Formula mass} = 156.71 \text{ amu}$$

(b) The chemical formula for urea contains parentheses. In the formula $(NH_2)_2CO$, the subscript 2 outside the parentheses affects both of the symbols inside the parentheses. One molecule of urea has 2 N atoms, 4 H atoms, 1 C atom, and 1 O atom.

$$\begin{array}{lrr} \text{N} & 2 \times 14.01 \text{ amu} = & 28.02 \text{ amu} \\ \text{H} & 4 \times 1.01 \text{ amu} = & 4.04 \text{ amu} \\ \text{C} & 1 \times 12.01 \text{ amu} = & 12.01 \text{ amu} \\ \text{O} & 1 \times 16.00 \text{ amu} = & \underline{16.00 \text{ amu}} \\ & (\text{NH}_2)_2\text{CO} = & 60.07 \text{ amu} \end{array}$$

Molar Mass

Atoms and molecules are so small that we are seldom able to deal with one of them at a time. When we weight even a very small amount of an element or compound, we are dealing with huge numbers of atoms or molecules.

Chemist resolved this problem by determining the exact number of carbon-12 atoms in exactly 12 g of carbon-12. There are exactly 6.022×10^{23} atoms of carbon-12 in exactly 12 g of carbon-12.

The number 6.022×10^{23} is known as Avogadro's number. Avogadro's number is an extremely large number and is very inconvenient to use. The counting unit called the mole, abbreviated mol, is used to represent 6.022×10^{23} objects.

The molar mass of any substance is the mass of one mole of any substance expressed in grams.

Molar mass also may be written in units as grams per mole, $\frac{g}{mol}$, that is the mass of the substance per mole of the substance.

For example: What is the molar mass for **(a)** tin (II) fluoride, SnF_2, and **(b)** urea, $(NH_2)_2CO$?

(a) One mole of SnF_2 contains 1 mole of Sn atom and 2 moles of F atoms

$$1 \text{ mol Sn} \times \left(\frac{118.71 \text{ g}}{1 \text{ mol Sn}}\right) = 118.71 \text{ g}$$

$$2 \text{ mol F} \times \left(\frac{19.00 \text{ g}}{1 \text{ g F}}\right) = \underline{38.00 \text{ g}}$$

$$1 \text{ mol } SnF_2 = 156.71 \text{ g}$$

$$\text{Molar mass of } SnF_2 = 156.71 \frac{\text{g}}{\text{mol}}$$

(b) One mole of urea has 2 mol N atoms, 4 mol H atoms, 1 mol C atom, and 1 mol O atom.

N	$2 \times 14.01 =$	28.02 g
H	$4 \times 1.01 =$	4.04 g
C	$1 \times 12.01 =$	12.01 g
O	$1 \times 16.00 =$	<u>16.00 g</u>

$$1 \text{ mol } (NH_2)_2CO = 60.07 \text{ g}$$

$$\text{Molar mass of urea} = 60.07 \frac{\text{g}}{\text{mol}}$$

1. Determine the molar mass of the following compounds.
   a. Methane, CH_4

   f. Methyl alcohol, CH_3OH

   j. Ammonium dichromate, $(NH_4)_2Cr_2O_7$

Mole-Mass Conversions
The molar mass of a substance is the conversion factor that allows us to convert between the mass of a substance (**in grams)** and the number of moles of that substance that are present. (Remember that one mole contains 6.022 x 10^{23} atoms, ions, molecules or formula units.)

To convert from grams to moles
Take the mass and divide by the molar mass of the substance.

For example: How many moles of H_2 are present in 14.7 g of H_2?

$$14.7g\ H_2\left(\frac{1\ mol\ H_2}{2.016g\ H_2}\right) = 7.29 mol\ H_2$$

To convert from moles to grams
Take the number of moles and multiply by the molar mass of the substance.

For example: How many mg of O_2 are present in 0.22 mol of O_2?

$$0.22 mol\ O_2\left(\frac{32.00g\ O_2}{1\ mol\ O_2}\right)\left(\frac{1000mg}{1g}\right) = 7.0\times 10^3\ mg\ O_2$$

1. Find the mass in grams for each of the following:
   a. 4.86 moles of B_2O_3

   d. 19.2 mol ammonium dichromate (use answer to 1j on A32)

   e. 0.136 mol of $C_6H_{12}O_6$

2. Find the number of moles in each of the following (make sure your formula is correct):
   a. 3.75 g of aluminum hydroxide

   b. 0.272 kg of magnesium nitride

   c. 42.42 g of argon

3. Find the number of atoms, formula units, or molecules in each of the following:
   a. molecules of glucose, $C_6H_{12}O_6$, in 0.136 mol of $C_6H_{12}O_6$

   c. atoms of helium in 7.85 g of He

   d. atoms of iodine in 229.6 mg of iodine, I_2, molecules (tricky)

Mole-Mole Conversions
The formula for a compound implies a ratio of the number of atoms in each formula unit or molecule of the compound. These ratios also apply to the number of moles of each atom in a mole of the compound. These ratios can be used to develop conversion factors for solving chemical problems.

For example, in the compound Ca_3P_2, every mole of Ca_3P_2 contains 3 moles of Ca and 2 moles of P. From this, the following 4-element/compound mole-mole conversion factors can be developed:

$$\frac{3\text{ mol Ca}}{1\text{ mol Ca}_3P_2} \qquad \frac{2\text{ mol P}}{1\text{ mol Ca}_3P_2} \qquad \frac{1\text{ mol Ca}_3P_2}{3\text{ mol Ca}} \qquad \frac{1\text{ mol Ca}_3P_2}{2\text{ mol P}}$$

2. How many moles of nitrogen atoms and how many moles of hydrogen atoms are present in 1.4 mol of $(NH_4)_3PO_4$?

3. Determine the mass of oxygen in each of the following compounds:
   a. 12.7 g of carbon dioxide

Stoichiometry

Just as the subscripts in the formula of a compound tell us how the quantities of atoms are related within a molecule, the stoichiometric coefficients in a balanced reaction tell us about how the quantities of reactant and product molecules (or formula units) are related to each other. These can also be setup as ratios or equalities to allow us to solve chemical calculations.

For example, in the reaction:

$$Al_2(SO_4)_3 + 3\ Ba(OH)_2 \rightarrow 3\ BaSO_4 + 2\ Al(OH)_3$$

The following 12 mole-mole relationships can be established:

$$\frac{1\text{ mol }Al_2(SO_4)_3}{3\text{ mol }Ba(OH)_2} \quad \frac{1\text{ mol }Al_2(SO_4)_3}{3\text{ mol }BaSO_4} \quad \frac{1\text{ mol }Al_2(SO_4)_3}{2\text{ mol }Al(OH)_3} \quad \frac{3\text{ mol }Ba(OH)_2}{3\text{ mol }BaSO_4} \quad \frac{3\text{ mol }Ba(OH)_2}{2\text{ mol }Al(OH)_3} \quad \frac{3\text{ mol }BaSO_4}{2\text{ mol }Al(OH)_3}$$

Plus the 6 reciprocals

2. Given: ____ $KClO_3$ (s) $\rightarrow$ _____ O_2 (g) + ____KCl (s)

   How many moles of KCl is produced when 12.5 mol $KClO_3$ is decomposed?

   How many moles of O_2 is produced when 12.5 mol KClO3 is decomposed?

3. The reaction ____ N_2(g) + ____ H_2(g)$\rightarrow$ _____ NH_3(g) is used to produce NH_3.

   How many moles of H_2(g) are required to produce 2.50 g of NH_3(g)?

   How many grams of N_2(g) are required to produce 2.50 g of NH3(g)?

5. Given: ____ $C_5H_{12}(l)$ + ____ $O_2(g)$ $\rightarrow$ ____ $CO_2(g)$ + ____ $H_2O(g)$ Calculate the grams of $O_2(g)$ gas needed to react with 2.00 mol of C_5H_{12}?

6. Given: ____ $N_2(g)$ + ____ $O_2(g)$ $\rightarrow$ ____ $N_2O_5(g)$ How many moles of $O_2(g)$ are needed to react with 1.250 moles of $N_2(g)$.

7. How many moles of $MgCl_2$ can be produced form 16.2 moles of HCl based on the following reaction?

   ____ Mg + ____ HCl $\rightarrow$ ____ $MgCl_2$ + ____ H_2

8. How many moles of Al would be required to produce 18.0 mol of H_2 according to the following unbalanced equation?

   ____ HCl + ____ Al $\rightarrow$ ____ H_2 + ____ $AlCl_3$

9. Consider the reaction: ____ S (s) +____ H_2SO_4 (aq) $\rightarrow$ ____ SO_2 (g) + ____ H_2O (l)

   4.80 g of sulfur reacts with excess sulfuric acid, what mass of water will be produced?