8.5: Mass-to-Mass Conversions

Learning Objectives

- Convert from mass or moles of one substance to mass or moles of another substance in a chemical reaction.

Mole-to-Mass Conversions

We have established that a balanced chemical equation is balanced in terms of moles, as well as atoms or molecules. We have used balanced equations to set up ratios, in terms of moles of materials, that we can use as conversion factors to answer stoichiometric questions – such as how many moles of substance A react with so many moles of reactant B. We can extend this technique even further. Recall that we can relate a molar amount to a mass amount using molar mass. We can use that relation to answer stoichiometry questions in terms of the masses of a particular substance, in addition to moles. We do this using the following sequence:

$$\boxed{\text{moles of A}} \xrightarrow[\text{ratio}]{\text{molar}} \boxed{\text{moles of B}} \xrightarrow[\text{mass}]{\text{molar}} \boxed{\text{grams of B}}$$

Collectively, these conversions are called *mole-to-mass* calculations. As an example, consider the balanced chemical equation

$$Fe_2O_3 + 3\ SO_3 \rightarrow Fe_2(SO_4)_3$$

Suppose we wanted to know how many grams of SO_3 will react with 3.59 mol of Fe_2O_3. Using the mole-mass calculation sequence, we can determine the required mass of SO_3 in two steps. First, we construct the appropriate *molar ratio*, determined from the balanced chemical equation, to calculate the number of moles of SO_3 needed. From here, the mass of SO_3 may be calculated using the *molar mass* of SO_3 as a conversion factor.

Relationship		Possible Conversions
molar ratio	1 mol Fe_2O_3: 3 mol SO_3	$\frac{1\text{ mol }Fe_2O_3}{3\text{ mol }SO_3}$ or $\frac{3\text{ mol }SO_3}{1\text{ mol }Fe_2O_3}$
molar mass	1 mol SO_3 = 80.07 g SO_3	$\frac{80.07\text{ g }SO_3}{1\text{ mol }SO_3}$ or $\frac{1\text{ mol }SO_3}{80.07\text{ g }SO_3}$

As before, start with the quantity given (3.59 mol Fe_2O_3):

$$3.59\ \text{mol}\ Fe_2O_3 \times \frac{3\ \text{mol}\ SO_3}{1\ \text{mol}\ Fe_2O_3} = 10.77\ \text{mol}\ SO_3$$

Moles of Fe_2O_3 cancel, leaving moles of SO_3 as the units. This answer may then be converted to grams of SO_3:

$$10.77\ \text{mol}\ SO_3 \times \frac{80.07\ \text{g}\ SO_3}{1\ \text{mol}\ SO_3} = \boxed{862\ \text{g}\ SO_3}$$

The final answer is expressed to three significant figures. Thus, in a two-step process, we find that 862 g of SO_3 will react with 3.59 mol of Fe_2O_3. Many problems of this type can be answered in this manner. It is generally easier if the problem is set up in a single series of steps:

$$3.59\ \text{mol}\ Fe_2O_3 \times \frac{3\ \text{mol}\ SO_3}{1\ \text{mol}\ Fe_2O_3} \times \frac{80.07\ \text{g}\ SO_3}{1\ \text{mol}\ SO_3} = \boxed{862\ \text{g}\ SO_3}$$

Notice that the identical answer is obtained, in much the same manner as when multi-step dimensional analysis was introduced in Section 2.7.

✅ Example 8.5.1: Generation of Aluminum Oxide

How many moles of HCl will be produced when 249 g of $AlCl_3$ are reacted according to this chemical equation?

$$2\ AlCl_3 + 3\ H_2O \rightarrow Al_2O_3 + 6\ HCl$$

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 249 g $AlCl_3$ Find: moles HCl
List other known quantities.	1 mol $AlCl_3$ = 133.33 g $AlCl_3$ 2 mol $AlCl_3$: 6 mol HCl
Prepare a concept map using the proper conversion factor(s).	$\boxed{\text{g AlCl}_3} \xrightarrow[133.33\ \text{g AlCl}_3]{1\ \text{mol AlCl}_3} \boxed{\text{mol AlCl}_3} \xrightarrow[2\ \text{mol AlCl}_3]{6\ \text{mol HCl}} \boxed{\text{mol HCl}}$
Cancel units and calculate.	$249\ \text{g}\ AlCl_3 \times \frac{1\ \text{mol}\ AlCl_3}{133.33\ \text{g}\ AlCl_3} \times \frac{6\ \text{mol HCl}}{2\ \text{mol}\ AlCl_3} = \boxed{5.60\ \text{mol HCl}}$
Think about your result.	249 g $AlCl_3$ is less than 266.66 g (the mass for 2 mol $AlCl_3$). Since the relationship is 6 mol HCl to 2 mol $AlCl_3$, the answer should be less than 6 mol HCl. The answer of 5.60 mol HCl is indeed less than 6 mol HCl.

✏️ Exercise 8.5.1: Generation of Aluminum Oxide

How many moles of Al_2O_3 will be produced when 23.9 g of H_2O are reacted according to this chemical equation?

$$2\ AlCl_3 + 3\ H_2O \rightarrow Al_2O_3 + 6\ HCl$$

Answer

0.442 mol Al_2O_3

Mass-to-Mass Conversions

In the real world, the number of molecules or moles are not measured directly. Rather, it is the masses of the reactants and/or products that will be measured directly. Consequently, it is much more practical to make all measurements in terms of the number of grams. It is a small step to move from *mole-to-mass* calculations to *mass-to-mass* calculations.

If we start with a known mass of one substance in a chemical reaction (instead of a known number of moles), we can calculate the corresponding masses of other substances in the reaction. The first step in this case is to convert the known mass into moles, using the substance's molar mass as the conversion factor. Then – and only then – the balanced chemical equation is used to construct a conversion factor to convert that quantity to moles of another substance, which in turn can be converted to a corresponding mass. Sequentially, the process is as follows:

$$\text{grams of A} \xrightarrow[\text{mass}]{\text{molar}} \text{moles of A} \xrightarrow[\text{ratio}]{\text{molar}} \text{moles of B} \xrightarrow[\text{mass}]{\text{molar}} \text{grams of B}$$

This three-part process can be carried out in three discrete steps or combined into a single calculation that contains three conversion factors. This text will generally approach this type of problem in a single series of steps.

✅ Example 8.5.2: Decomposition of Ammonium Nitrate

Ammonium nitrate decomposes to dinitrogen monoxide and water according to the following equation.

$$NH_4NO_3\ (s) \rightarrow N_2O\ (g) + 2\ H_2O\ (l)$$

Find the mass of each product formed when 45.7 g of ammonium nitrate is decomposed.

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 45.7 g NH_4NO_3 Find: Mass N_2O, Mass H_2O
List other known quantities.	1 mol NH_4NO_3 = 80.05 g NH_4NO_3 1 mol N_2O = 44.02 g N_2O 1 mol H_2O = 18.02 g H_2O 1 mol NH_4NO_3: 1 mol N_2O 1 mol NH_4NO_3: 2 mol H_2O
Prepare concept maps using the proper conversion factor(s).	$\text{g } NH_4NO_3 \xrightarrow[80.05\ \text{g } NH_4NO_3]{1\ \text{mol } NH_4NO_3} \text{mol } NH_4NO_3 \xrightarrow[1\ \text{mol } NH_4NO_3]{1\ \text{mol } N_2O} \text{mol } N_2O$ $\text{g } NH_4NO_3 \xrightarrow[80.05\ \text{g } NH_4NO_3]{1\ \text{mol } NH_4NO_3} \text{mol } NH_4NO_3 \xrightarrow[1\ \text{mol } NH_4NO_3]{2\ \text{mol } H_2O} \text{mol } H_2O$
Cancel units and calculate.	$45.7\ \cancel{\text{g } NH_4NO_3} \times \frac{1\ \cancel{\text{mol } NH_4NO_3}}{80.05\ \cancel{\text{g } NH_4NO_3}} \times \frac{1\ \cancel{\text{mol } N_2O}}{1\ \cancel{\text{mol } NH_4NO_3}} \times \frac{44.02\ \text{g } N_2O}{1\ \cancel{\text{mol } N_2O}} = \boxed{25.1\ \text{g } N_2O}$ $45.7\ \cancel{\text{g } NH_4NO_3} \times \frac{1\ \cancel{\text{mol } NH_4NO_3}}{80.05\ \cancel{\text{g } NH_4NO_3}} \times \frac{2\ \cancel{\text{mol } H_2O}}{1\ \cancel{\text{mol } NH_4NO_3}} \times \frac{18.02\ \text{g } H_2O}{1\ \cancel{\text{mol } H_2O}} = \boxed{20.6\ \text{g } H_2O}$
Think about your result.	The sum of the masses of the two products is equal to the mass of ammonium nitrate decomposed. This demonstrates the Law of Conservation of Mass. Each answer has three significant figures.

✏️ Exercise 8.5.2: Carbon Tetrachloride

Methane reacts with elemental chlorine to make carbon tetrachloride, CCl_4. The balanced chemical equation for this reaction is:

$$CH_4\ (g) + 4\ Cl_2\ (g) \rightarrow CCl_4\ (l) + 4\ HCl\ (g)$$

How many grams of HCl are produced by the reaction of 100.0 g CH_4?

Answer

909.1 g HCl

✅ Example 8.5.3: Production of Ammonia

Taking into consideration the balanced chemical equation:

$$N_2\,(g) + 3\,H_2\,(g) \rightarrow 2\,NH_3\,(g)$$

what mass of hydrogen gas is needed to prepare 404 g of ammonia?

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 404 g NH_3 Find: Mass H_2
List other known quantities.	1 mol NH3 = 17.03 g NH_3 1 mol H_2 = 2.016 g H_2 3 mol H_2: 2 mol NH_3
Prepare concept maps using the proper conversion factor(s).	$\boxed{\text{g } NH_3} \xrightarrow[17.03\ \text{g } NH_3]{1\ \text{mol } NH_3} \boxed{\text{mol } NH_3} \xrightarrow[2\ \text{mol } NH_3]{3\ \text{mol } H_2} \boxed{\text{mol } H_2} \xrightarrow[1\ \text{mol } H_2]{2.016\ \text{g } H_2} \boxed{\text{g } H_2}$
Cancel units and calculate.	$404\ \cancel{\text{g } NH_3} \times \frac{1\ \cancel{\text{mol } NH_3}}{17.03\ \cancel{\text{g } NH_3}} \times \frac{3\ \cancel{\text{mol } H_2}}{2\ \cancel{\text{mol } NH_3}} \times \frac{2.016\ \text{g } H_2}{1\ \cancel{\text{mol } H_2}} = \boxed{71.7\ \text{g } H_2}$
Think about your result.	404 g NH_3 is a bit more than 20 mol N_3. Since the molar ratio is 3 mol H_2: 2 mol NH_3, a bit more than 30 mol H_2 are needed. 71.7 g H_2 is a bit more than 30 mol H_2.

✏️ Exercise 8.5.3: Vanadium(V) Oxide

Vanadium metal reacts with oxygen gas to yield solid vanadium(V) oxide:

$$4\,V\,(s) + 5\,O_2\,(g) \rightarrow 2\,V_2O_5\,(s)$$

A. What is the molar ratio between V and O_2?
B. How many moles of V will react with 9.25 mol O_2?
C. What mass of vanadium is needed to produce 0.301 g V_2O_5?

Answer A

4 mol V: 5 mol O_2

Answer B

7.40 mol V

Answer C

0.169 g V

Summary

- Calculations involving conversions between moles of a substance and the mass of that substance can be done using conversion factors.
- A balanced chemical reaction can be used to determine molar and mass relationships between substances.