Chapter 3.7 Limiting Reactants

Calculating the yield of a chemical reaction is a process at the heart of chemistry. While there are many ways a problem can be phrased, in all cases the *stoichiometric coefficients* in the balanced reaction are used to determine the *mole ratios* between reactants and products. Thus the *first step* is usually *calculating the moles of each species available*. If an amount is given in grams, the molar mass is used as a conversion factor to change grams to moles.

Limiting Reagent Problems

In some problems, amounts of *more than one* species are given. In that case your first task is to determine which species is the *limiting reagent*. Just as you can make only 1 bicycle from 2 wheels and 4 handlebars (with 3 handlebars left over), and only 2 bicycles from 8 wheels and 2 handlebars (with 4 wheels left over), in chemical reactions some species are *limiting* while others may be *present in excess*.

In the case of a bicycle, we need $\left(\dfrac{\text{2 wheels}}{\text{1 handlebar}}\right)$. We obtain analogous information about the relative amounts of species that react from the *stoichiometric coefficients* in a balanced chemical equation. For example, in Exercise (2) below the equation

$$CO(g) + 2\,H_2(g) \rightarrow CH_3OH(l)$$

tells us we need $\left(\dfrac{\text{2 mol } H_2}{\text{1 mol CO}}\right)$. If we have *more* than 2 moles of H_2 for each mole of CO, CO will be the *limiting reagent* and the excess H_2 will not react. Conversely, if we have *more* than 1 mole of CO for every 2 moles of H_2, H_2 will be the *limiting reagent* and the excess CO(g) will be left over. In each case, the yield of CH_3OH is determined by the moles of limiting reagent available.

Calculating the Theoretical Yield

The theoretical (maximum possible) yield is based on the amount of limiting reagent available. The yield is calculated in steps:

- Calculate *moles* of all reactants *available*. If amounts are given in grams, convert grams to moles using the *molar mass* of each reactant as your conversion factor: $\left(\dfrac{\text{1 mole reactant}}{\text{\# g reactant}}\right)$.
- **NOTE**: Skip this step if you have already identified the limiting reagent. To determine which reagent is limiting, use the *mole ratio* obtained from the balanced equation for the reaction to find the *moles of reactant B needed* to react with the *available* moles of reactant A. If the moles of B *available* is *less* than the moles of B *needed*, reactant B is the *limiting reagent* and reactant A is in excess. Conversely, if the moles of B *available* is *more* than the moles of B *needed*, A is the *limiting reagent* and B is in excess.
- Calculate the *moles* of product *based on the moles of limiting reagent available*; use the stoichiometric ratio of $\left(\dfrac{\text{\# moles product}}{\text{\# moles limiting reagent}}\right)$ as the conversion factor.
- If you are asked for the yield in grams, convert the yield in moles to a yield in grams using the *molar mass* as your conversion factor: $\left(\dfrac{\text{\# g product}}{\text{1 mole product}}\right)$

Percent Yield

Most reactions do not go to completion, and so the actual yield is less than the percent yield. The percent yield is calculated as

$$\text{Percent yield} = \left(\frac{\text{actual yield}}{\text{theoretical yield}}\right) \times 100\%$$

Practice Problem #1

1) Write the balanced equation for the reaction of lead (II) nitrate with sodium iodide to form sodium nitrate and lead (II) iodide:

2) If I start with 25.0 grams of lead (II) nitrate and 15.0 grams of sodium iodide, how many grams of sodium nitrate can be formed?

3) What is the limiting reagent in the reaction described in problem 2?

4) How much of the nonlimiting reagent will be left over from the reaction in problem #2?

Practice Problem #2

1. Ammonia is produced by the reaction

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

(a) If $N_2(g)$ is present in excess and 55.6 g of $H_2(g)$ reacts, what is the *theoretical yield* of $NH_3(g)$?

(b) What is the *percent yield* if the actual yield of the reaction is 159 g of $NH_3(g)$?

Practice Problem #3

Methyl alcohol (wood alcohol), CH_3OH, is produced via the reaction

$$CO(g)\ +\ 2\ H_2(g)\ \rightarrow\ CH_3OH(l)$$

A mixture of 1.20 g $H_2(g)$ and 7.45 g CO(g) are allowed to react.
(a) Which reagent is the *limiting reagent*?

(b) What is the yield of CH_3OH? [Assume theoretical yield in g is what is wanted here.]

(c) How much of the reagent present in excess is left over?

(d) Suppose the actual yield is 7.52 g of CH_3OH. What is the % yield?

Practice Problem #4

Automotive airbags inflate when sodium azide, NaN_3, rapidly decomposes to its component elements:

$$2NaN_{3(s)} \rightarrow Na_{(s)} + 3N_{2(g)}$$

(a) How many moles of N_2 are produced by the decomposition of 1.50 moles of NaN_3?

(b) How many grams of NaN_3 are required to form 5.00 g of nitrogen gas?

Practice Problem #5

Hydrofluoric acid, HF(aq), cannot be stored in glass bottles because compounds called silicates in the glass are attacked by the HF(aq). For example, sodium silicate, Na_2SiO_3, reacts in the following way:

$$Na_2SiO_{3(s)} + 8HF_{(aq)} \rightarrow H_2SiF_{6(aq)} + 2NaF_{(aq)} + 3H_2O_{(l)}$$

(a) How many moles of HF(aq) are required to dissolve 0.50 mol of $Na_2SiO_{3(s)}$?

(b) How many grams of NaF(aq) form when 0.300 mol of HF reacts in this way?

(c) Determine the limiting reactant if 10.5 grams of Na_2SiO_3 and 167.0 grams of HF react.

(d) Using the above amounts, how many grams of water will be formed?

(e) How much of the reagent present in excess is left over?