8.6: Limiting Reactants and Excess Reactants

Learning Objectives

- Identify the limiting reactant (limiting reagent) in a given chemical reaction.
- Calculate how much product will be produced from the limiting reactant.
- Calculate how much reactant(s) remains when the reaction is complete.

Section 8.2 used an automobile factory to introduce terminology that extends to the stoichiometry associated with chemical reactions. We learned that the **limiting reactant** is the reactant that limits the amount of product that can be made, while an **excess reactant** is one that is not entirely consumed. We also learned that the **theoretical yield** is the maximum amount of product that may be made when all of the limiting reactant is converted to product.

Check out the simulation below for examples that review the concept of limiting reactants and excess reactants and applies the concept to making sandwiches and molecules. Then test your understanding with a game.

PhET Simulation: Limiting and Excess Reactants

View this interactive simulation illustrating the concepts of limiting and excess reactants.

Consider the reaction between hydrogen and chlorine to make hydrogen chloride:

$$H_2\,(g) + Cl_2\,(g) \rightarrow 2\,HCl\,(g)$$

The balanced equation shows that hydrogen and chlorine react in a 1:1 stoichiometric ratio. If these reactants are provided in any other amounts, one of the reactants will nearly always be entirely consumed, thus limiting the amount of product that may be generated. This substance is the limiting reactant, and the other substance is the excess reactant. Identifying the limiting and excess reactants for a given situation requires computing the molar amounts of each reactant provided and comparing them to the stoichiometric amounts represented in the balanced chemical equation.

For example, imagine combining 3 moles of H_2 and 2 moles of Cl_2. This represents a 3:2 (or 1.5:1) ratio of hydrogen to chlorine present for reaction, which is greater than the stoichiometric ratio of 1:1. Hydrogen, therefore, is present in excess, and chlorine is the limiting reactant. Reaction of all of the provided chlorine (2 moles) will consume 2 of the 3 moles of hydrogen provided, leaving 1 mole of hydrogen that is unconsumed (see Figure 8.6.1).

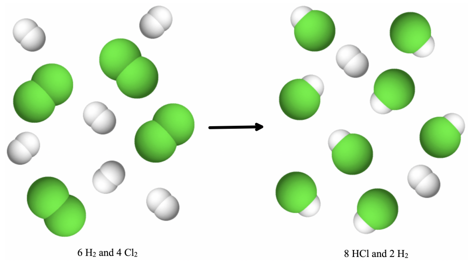

Figure 8.6.1: When H_2 and Cl_2 are combined in non-stoichiometric amounts, one of these reactants will limit the amount of HCl that can be produced. This illustration shows a reaction in which hydrogen is present in excess and chlorine is the limiting reactant.

An alternative approach to identifying the limiting reactant involves comparing the amount of product expected for the complete reaction of each reactant. Each reactant amount is used to separately calculate the amount of product that would be formed per the reaction's stoichiometry. The reactant yielding the lesser amount of product is the limiting reactant.

If we were to again imagine combining 3 moles of H_2 and 2 moles of Cl_2, complete reaction of the provided hydrogen would yield:

$$3\ \text{mol}\ \cancel{H_2} \times \frac{2\ \text{mol HCl}}{1\ \text{mol}\ \cancel{H_2}} = 6\ \text{mol HCl produced}$$

Complete reaction of the provided chlorine would produce:

$$2\ \text{mol}\ \cancel{Cl_2} \times \frac{2\ \text{mol HCl}}{1\ \text{mol}\ \cancel{Cl_2}} = \boxed{4\ \text{mol HCl produced}}$$

The chlorine will be completely consumed once 4 moles HCl have been produced. Since enough hydrogen was provided to yield 6 moles HCl, there will be hydrogen that remains unconsumed once this reaction is complete.

A similar situation exists for many chemical reactions: you usually run out of one reactant before all of the other reactant has reacted. The reactant that is entirely consumed is called the limiting reactant; the other reactant or reactants are present *in excess*. A crucial skill in evaluating the conditions of a chemical process is to determine which reactant is the limiting reactant and which is/are the excess reactant(s).

The key to recognizing which reactant is the limiting reactant is to determine the reactant that yields the *least* amount of product is the limiting reactant. It doesn't matter which product is used for the calculation, as long as the same product is used in for the comparison. It also doesn't matter whether the number of moles or grams of that product is calculated. However, knowing the final mass of product is generally more useful.

✅ Example 8.6.1: Limiting Reactants and Mole-to-Mole Calculations

Consider the balanced equation:

$$4\ C_2H_3Br_3 + 11\ O_2 \rightarrow 8\ CO_2 + 6\ H_2O + 6\ Br_2$$

A. How many moles of Br_2 could be produced when 36 mol $C_2H_3Br_3$ are reacted with 33 mol O_2?
B. Identify the limiting reactant(s) and excess reactant(s).

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 36 mol $C_2H_3Br_3$ reacted; 33 mol O_2 reacted Find: theoretical yield Br_2; identify limiting reactant(s) and excess reactant(s)
List other known quantities.	4 mol $C_2H_3Br_3$: 6 mol Br_2 11 mol O_2: 6 mol Br_2
Prepare concept maps using the proper conversion factor(s).	$\boxed{\text{mol } C_2H_3Br_3} \xrightarrow[4\ \text{mol}\ C_2H_3Br_3]{6\ \text{mol}\ Br_2} \boxed{\text{mol } Br_2}$ $\boxed{\text{mol } O_2} \xrightarrow[11\ \text{mol}\ O_2]{6\ \text{mol}\ Br_2} \boxed{\text{mol } Br_2}$
Calculate the theoretical yield. Select the smallest answer.	$36\ \text{mol}\ \cancel{C_2H_3Br_3} \times \frac{6\ \text{mol}\ \cancel{Br_2}}{4\ \text{mol}\ \cancel{C_2H_3Br_3}} = \cancel{54\ \text{mol}\ Br_2}$ $33\ \text{mol}\ \cancel{O_2} \times \frac{6\ \text{mol}\ \cancel{Br_2}}{11\ \text{mol}\ \cancel{O_2}} = \boxed{18\ \text{mol}\ Br_2}$

Steps for Problem Solving	
Identify the limiting reactant(s) and excess reactant(s).	The limiting reactant is O_2 since it would yield the least amount of product (18 mol Br_2). The excess reactant is $C_2H_3Br_3$ since its complete reaction would have yielded up to 54 mol Br_2.
Think about your result.	It usually is not possible to determine the limiting reactant looking at the initial amounts, since the reactants have different coefficients.

✅ Example 8.6.2: Limiting Reactants and Mass-to-Mass Calculations

Consider once again the balanced equation:

$$4\ C_2H_3Br_3 + 11\ O_2 \rightarrow 8\ CO_2 + 6\ H_2O + 6\ Br_2$$

A. What is the theoretical yield of CO_2, in grams, when 76.4 grams of $C_2H_3Br_3$ are reacted with 49.1 grams of O_2?
B. Identify the limiting reactant(s) and excess reactant(s).

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 76.4 g $C_2H_3Br_3$ reacted; 49.1 g O_2 reacted Find: theoretical yield CO_2; identify limiting reactant(s) and excess reactant(s)
List other known quantities.	1 mol $C_2H_3Br_3$ = 266.74 g $C_2H_3Br_3$ 1 mol O_2 = 32.00 g O_2 1 mol CO_2 = 44.01 g CO_2 4 mol $C_2H_3Br_3$: 8 mol CO_2 11 mol O_2: 8 mol CO_2
Prepare concept maps using the proper conversion factor(s).	$\boxed{\text{g } C_2H_3Br_3} \xrightarrow[\text{266.74 g } C_2H_3Br_3]{\text{1 mol } C_2H_3Br_3} \boxed{\text{mol } C_2H_3Br_3} \xrightarrow[\text{4 mol } C_2H_3Br_3]{\text{8 mol } CO_2} \boxed{\text{mol } CO_2}$ $\boxed{\text{g } O_2} \xrightarrow[\text{32.00 g } O_2]{\text{1 mol } O_2} \boxed{\text{mol } O_2} \xrightarrow[\text{11 mol } O_2]{\text{8 mol } CO_2} \boxed{\text{mol } CO_2} \xrightarrow[\text{1 mol } CO_2]{\text{44.01 g } CO_2}$
Calculate the theoretical yield. Select the smallest answer.	$76.4\ \cancel{\text{g } C_2H_3Br_3} \times \frac{1\ \cancel{\text{mol } C_2H_3Br_3}}{266.74\ \cancel{\text{g } C_2H_3Br_3}} \times \frac{8\ \cancel{\text{mol } CO_2}}{4\ \cancel{\text{mol } C_2H_3Br_3}} \times \frac{44.01\text{ g } CO_2}{1\ \cancel{\text{mol } CO_2}} = \boxed{25.2\text{ g } CO_2}$ $49.1\ \cancel{\text{g } O_2} \times \frac{1\ \cancel{\text{mol } O_2}}{32.00\ \cancel{\text{g } O_2}} \times \frac{8\ \cancel{\text{mol } CO_2}}{11\ \cancel{\text{mol } O_2}} \times \frac{44.01\text{ g } CO_2}{1\ \cancel{\text{mol } CO_2}} = \cancel{49.1\text{ g } CO_2}$
Identify the limiting reactant(s) and excess reactant(s).	The limiting reactant is $C_2H_3Br_3$ since it would yield the least amount of product (25.2 g CO_2). The excess reactant is O_2 since its complete reaction would have yielded up to 49.1 g CO_2.
Think about your result.	It usually is not possible to determine the limiting reactant looking at the initial masses, since the reactants have different molar masses and different coefficients.

✅ Example 8.6.3: Limiting Reactant and Mass of Excess Reactant

5.00 g Rb are combined with 3.44 g $MgCl_2$ according to the chemical reaction:

$$2\ Rb\ (s) + MgCl_2\ (s) \rightarrow Mg\ (s) + 2\ RbCl\ (s)$$

A. What mass of Mg is formed?
B. What mass of which reactant is left over?

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 5.00 g Rb reacted; 3.44 g $MgCl_2$ reacted Find: theoretical yield Mg; identify excess reactant and its mass
List other known quantities.	1 mol Rb = 85.47 g Rb 1 mol $MgCl_2$ = 95.21 g $MgCl_2$ 1 mol Mg = 24.31 g Mg 2 mol Rb: 1 mol Mg 1 mol $MgCl_2$: 1 mol Mg
Prepare concept maps using the proper conversion factor(s).	$\boxed{\text{g Rb}} \xrightarrow[85.47\ \text{g Rb}]{1\ \text{mol Rb}} \boxed{\text{mol Rb}} \xrightarrow[2\ \text{mol Rb}]{1\ \text{mol Mg}} \boxed{\text{mol Mg}} \xrightarrow[1\ \text{mol Mg}]{24.31\ \text{g Mg}} \boxed{\text{g Mg}}$ $\boxed{\text{g } MgCl_2} \xrightarrow[95.21\ \text{g } MgCl_2]{1\ \text{mol } MgCl_2} \boxed{\text{mol } MgCl_2} \xrightarrow[2\ \text{mol } MgCl_2]{1\ \text{mol Mg}} \boxed{\text{mol Mg}} \xrightarrow[1\ \text{mol Mg}]{24.31\ \text{g Mg}}$
Calculate the theoretical yield. Select the smallest answer.	$5.00\ \text{g}\ \cancel{\text{Rb}} \times \frac{1\ \cancel{\text{mol Rb}}}{85.47\ \text{g}\ \cancel{\text{Rb}}} \times \frac{1\ \cancel{\text{mol Mg}}}{2\ \cancel{\text{mol Rb}}} \times \frac{24.31\ \text{g Mg}}{1\ \cancel{\text{mol Mg}}} = \boxed{0.711\ \text{g Mg}}$ $3.44\ \text{g}\ \cancel{MgCl_2} \times \frac{1\ \cancel{\text{mol } MgCl_2}}{95.21\ \text{g}\ \cancel{MgCl_2}} \times \frac{1\ \cancel{\text{mol Mg}}}{1\ \cancel{\text{mol } MgCl_2}} \times \frac{24.31\ \text{g Mg}}{1\ \cancel{\text{mol Mg}}} = \cancel{0.878\ \text{g Mg}}$
Identify the limiting reactant(s) and excess reactant(s).	The limiting reactant is Rb since it would yield the least amount of product (0.711 g Mg). The excess reactant is $MgCl_2$ since its complete reaction would have yielded up to 0.878 g Mg.
Calculate the mass of excess reactant that reacts.	Start with 5.00 g Rb, since it is the limiting reactant and known to completely react. $5.00\ \text{g}\ \cancel{\text{Rb}} \times \frac{1\ \cancel{\text{mol Rb}}}{85.47\ \text{g}\ \cancel{\text{Rb}}} \times \frac{1\ \cancel{\text{mol } MgCl_2}}{2\ \cancel{\text{mol Rb}}} \times \frac{95.21\ \text{g } MgCl_2}{1\ \cancel{\text{mol } MgCl_2}} = \boxed{2.78\ \text{g } MgCl_2\ \text{reacted}}$
Calculate the mass of excess reactant that remains and think about the result.	We started with 3.44 g $MgCl_2$ and found that 2.78 g $MgCl_2$ reacted. This makes sense, since $MgCl_2$ is the excess reactant. Less should react than we started with. 3.44 g $MgCl_2$ initially – 2.78 g $MgCl_2$ reacted = 0.66 g $MgCl_2$ remain

✏️ Exercise 8.6.1

Given the balanced chemical equation:

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

A. If 24.5 moles of C_8H_{18} are reacted with 245 moles of O_2, how many moles of CO_2 are produced assuming complete reaction?
B. How many moles of which reactant remain unconsumed?

Answer A

157 mol CO_2 are produced.

Answer B

4.9 mol C_8H_{18} remain unconsumed.

✏️ Exercise 8.6.2

Potassium superoxide, KO_2, is used in rebreathing gas masks to generate oxygen according to the equation below.

$$4\ KO_2\ (s) + 2\ H_2O\ (l) \rightarrow 4\ KOH\ (s) + 3\ O_2\ (g)$$

A. What is the theoretical yield of oxygen, in units of grams, when 108 g of KO_2 reacts with 16.8 g of H_2O?
B. Which reactant is the limiting reactant?
C. Which reactant is present in excess?

Answer A

36.5 g O_2 are produced.

Answer B

The limiting reactant is KO_2.

Answer C

H_2O is present in excess.