SECTION 7.2

Limiting and Excess Reactants

Key Terms

stoichiometric amount
limiting reactant
excess reactant

Consider again the turkey sandwich example in **Figure 7.1**. The recipe for a turkey sandwich can be written as an equation:

2 toast slices + 2 turkey slices + 1 lettuce leaf + 1 tomato slice → 1 turkey sandwich

A certain number of each ingredient is necessary to make a turkey sandwich according to the recipe. However, there is always the possibility that there will be a short supply of at least one ingredient. When an ingredient runs out, the production of turkey sandwiches by the recipe stops. In other words, the ingredient that runs out first limits the quantity of sandwiches that can be produced. For example, suppose that you have four toast slices, six turkey slices, three lettuce leaves, and three tomato slices, as shown in **Figure 7.6**. Because each sandwich requires two slices of toast, you can make only two sandwiches, even though you have enough of the other ingredients to make three turkey sandwiches. The number of slices of toast limits the number of sandwiches you can make. The other ingredients are in excess and are left over.

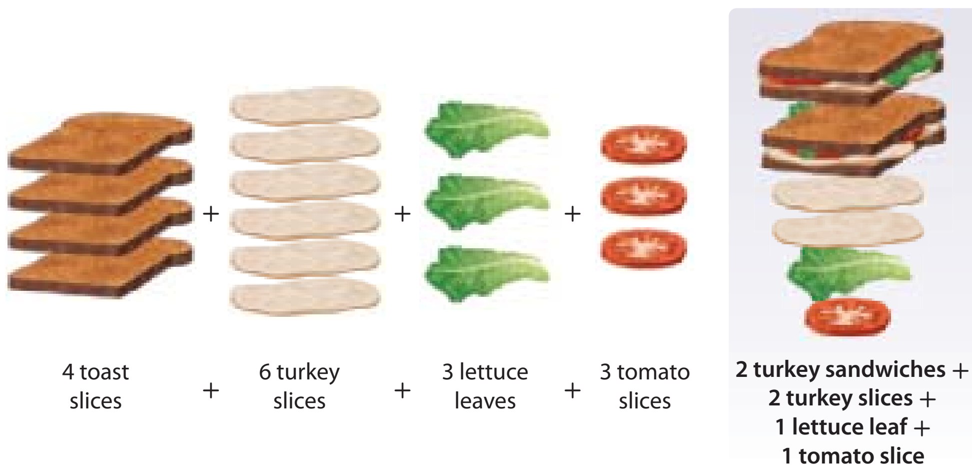


Figure 7.6 Once you make two turkey sandwiches, there is no more toast to make additional sandwiches. Toast is the "limiting ingredient." The other ingredients are in excess and are left over.

Limiting and Excess Reactants in Chemical Reactions

If the reactants in a chemical reaction are present in amounts that correspond exactly to the mole ratios from the balanced chemical equation, they are said to be present in **stoichiometric amounts**. If the reactants are present in stoichiometric amounts, ideally the reaction stops when no trace of the reactants are left. However, in actual chemical reactions, one reactant is usually in shorter supply than the other reactants. In other words, it is rare for the reactants in a chemical reaction to be present in amounts that correspond exactly to the mole ratios from the balanced chemical equation. In most reactions, there is at least one leftover reactant when the chemical reaction stops.

Consider a candle burning in a room. There is an unlimited amount of oxygen in the air, so the reaction proceeds until the wax is gone. However, if a candlesnuffer, like the one in **Figure 7.7,** is put over the burning candle, the amount of oxygen is limited. The combustion reaction stops when the supply of oxygen is gone, even though there is wax available. The reactant that limits or stops a reaction, such as the oxygen in **Figure 7.7,** is called the **limiting reactant** or limiting reagent. The limiting reactant determines the amount of product that is formed. The reactants that are left over, such as the candle wax, are called **excess reactants**.

stoichiometric amount the exact molar amount of a reactant or product, as predicted by a balanced chemical equation

limiting reactant a reactant that is completely consumed during a chemical reaction, limiting the amount of product that is produced

excess reactant a reactant that remains after a reaction is over

The Limiting Reactant Forms Less Product

The limiting reactant is not necessarily the reactant that is present in the smaller amount. It is the reactant that forms the smaller amount of product. For example, consider the chemical reaction that produces water:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

If oxygen is present in excess and 2 mol of hydrogen is available, then 2 mol of water is produced. However, if hydrogen is in excess and 2 mol of oxygen is available, then 4 mol of water is produced. In each situation, the limiting reactant is the reactant that forms the smaller amount of product. Similarly, the limiting reactant is not necessarily the reactant that has the lower mass. It is the reactant that produces the lower mass of product.

Figure 7.7 There was excess oxygen available for the burning candle until a candlesnuffer was used to limit the oxygen.

Identifying the Limiting Reactant in a Chemical Reaction

It is important to identify the limiting and excess reactants. This is because the amount of limiting reactant that is available for a chemical reaction determines the amount of product that is formed and the amount of excess reactant that is left over. To identify the limiting reactant, you need to determine which reactant yields the smaller amount of product in a chemical reaction. The activity below demonstrates the importance of considering the limiting reactant.

Suggested Investigation

Inquiry Investigation 7-A, Limiting and Excess Reactants

Activity 7.2 Identify the Limiting Item

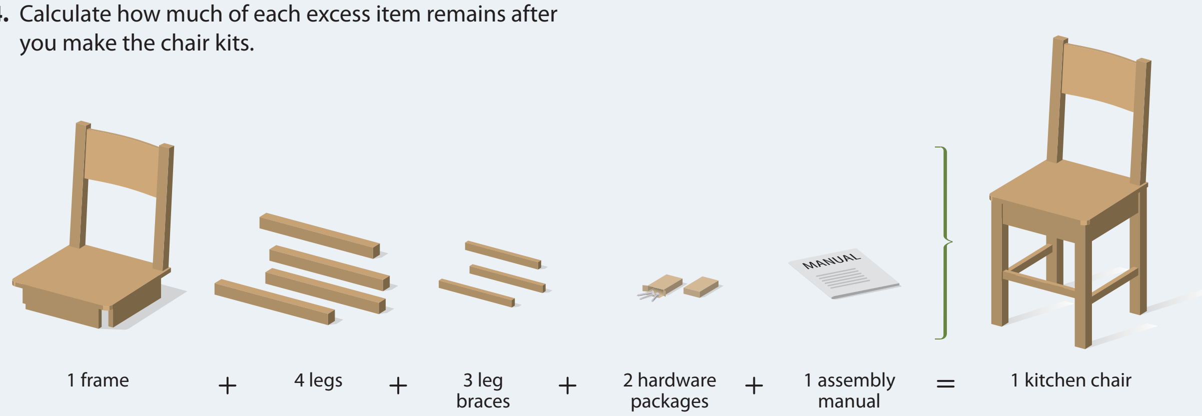
Suppose that you have been hired by a furniture company. Your job is to put together kits for making kitchen chairs. Each kit contains all the parts that are needed to assemble one kitchen chair. The equation for one kitchen chair is given below.

Procedure

1. Assume that you have 36 frames, 128 legs, 256 leg braces, 100 hardware packages, and 1000 assembly manuals. How many complete chair kits can you make?
2. Determine the item that will limit the number of complete chair kits you can make.
3. Determine the items you have in excess amounts.
4. Calculate how much of each excess item remains after you make the chair kits.

Questions

1. You have 36 chair frames. Why are the chair frames not the limiting item, even though they are present in the smallest quantity?
2. Does an item that is available in excess affect the quantity of complete chair kits that you can make? Explain your answer.



Identifying the Limiting Reactant in Problems

When solving problems, it is important to identify which reactant is limiting. The Sample Problem below demonstrates how to identify the limiting reactant.

Sample Problem

Identifying the Limiting Reactant

Problem

The chemical compound ammonia is prepared from its elements according to the following chemical equation:

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

The production of ammonia is an important industrial process in the manufacture of fertilizers. If 4.20 g of nitrogen gas reacts with 0.750 g of hydrogen gas, which is the limiting reactant?

What Is Required?

You need to determine whether nitrogen gas or hydrogen gas is the limiting reactant.

What Is Given?

You know the balanced chemical equation:

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

You know the mass of nitrogen: 4.20 g

You know the mass of hydrogen: 0.750 g

Plan Your Strategy	Act on Your Strategy
Calculate the molar masses, M, of nitrogen and hydrogen.	$M_{N_2} = 2M_N = 2\left(\frac{14.01 g\ N}{1\ mol}\right) = 28.02\ g/mol$ $M_{H_2} = 2M_H = 2\left(\frac{1.01 g\ H}{1\ mol}\right) = 2.02\ g/mol$
Convert the masses of nitrogen and hydrogen into amounts (in moles) using $n = \frac{m}{M}$.	$n_{N_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{4.20\ \cancel{g}}{28.02\ \cancel{g}/mol} = 0.14989\ mol\ N_2(g)$ $n_{H_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{0.750\ \cancel{g}}{2.02\ \cancel{g}/mol} = 0.37129\ mol\ H_2(g)$
Calculate the amount of ammonia that is produced by the given amount of nitrogen and the given amount of hydrogen.	$n_{NH_3} = 0.14989\ \cancel{mol\ N_2} \times \frac{2\ mol\ NH_3}{1\ \cancel{mol\ N_2}} = 0.300\ mol\ NH_3$ $n_{NH_3} = 0.37129\ \cancel{mol\ H_2} \times \frac{2\ mol\ NH_3}{3\ \cancel{mol\ H_2}} = 0.248\ mol\ NH_3$
Compare the amounts of ammonia that are produced by nitrogen and hydrogen to determine the limiting reactant.	The given amount of hydrogen produces less ammonia than the given amount of nitrogen. Therefore, the limiting reactant is hydrogen gas. Notice that there is more hydrogen gas than nitrogen gas, in terms of moles. Hydrogen gas is the limiting reactant, however, because 3 mol of hydrogen gas is needed to react with 1 mol of nitrogen gas.

Check Your Solution

According to the balanced chemical equation, the ratio of nitrogen to hydrogen is 1:3. The ratio of nitrogen to hydrogen, based on the amounts calculated, is 0.15:0.37. Divide this ratio by 0.15 to get 1:2.47. For each mole of nitrogen, there is only 2.47 mol of hydrogen. However, 3 mol is required by stoichiometry. Therefore, hydrogen gas is the limiting reactant.

Practice Problems

31. Hydrogen fluoride, $HF(g)$, is a highly toxic gas. It is produced according to the following balanced chemical equation:

$$CaF_2(s) + H_2SO_4(aq) \rightarrow 2HF(g) + CaSO_4(s)$$

Determine the limiting reactant when 1.00 g of calcium fluoride, $CaF_2(s)$, reacts with 15.5 g of sulfuric acid, $H_2SO_4(aq)$.

32. An ester is an organic compound that forms when a carboxylic acid reacts with an alcohol. Esters often are used as essences or scents. One such ester is methyl salicylate, $C_8H_8O_3(aq)$, which is oil of wintergreen. It is formed by the reaction of salicylic acid, $C_7H_6O_3(aq)$, and methanol, $CH_3OH(aq)$, as shown below:

$$C_7H_6O_3(aq) + CH_3OH(aq) \rightarrow C_8H_8O_3(aq) + H_2O(\ell)$$

If 100.11 g of salicylic acid and 90.4 g of methanol are used to produce oil of wintergreen, which is the limiting reactant?

33. Acetylene, $C_2H_2(g)$, is used in welding. It forms when calcium carbide, $CaC_2(s)$, reacts with water, as shown below:

$$CaC_2(s) + 2H_2O(\ell) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$$

If 5.50 mol of calcium carbide reacts with 3.75 mol of water, which is the limiting reactant?

34. Nickel(II) chloride, $NiCl_2(aq)$, reacts with sodium phosphate, $Na_3PO_4(aq)$, according to the following balanced chemical equation:

$$3NiCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Ni_3(PO_4)_2(s) + 6NaCl(aq)$$

If 10.0 g of each reactant is used, which is the limiting reactant?

35. Copper metal reacts with nitric acid, $HNO_3(aq)$, as follows:

$$3Cu(s) + 8HNO_3(aq) \rightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(\ell)$$

If 2.5 g of copper reacts with 25.0 g of nitric acid, which reactant is in excess?

36. Lithium reacts with oxygen to form lithium oxide, $Li_2O(s)$.

$$4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$$

When 20.0 g of lithium metal reacts with 30.0 g of oxygen gas, which reactant is limiting and which reactant is in excess?

37. Chlorine gas is used in the textile industry to bleach fabric. Excess chlorine is removed by a reaction with sodium thiosulfate, $Na_2S_2O_3(aq)$, as shown below:

$$Na_2S_2O_3(aq) + 4Cl_2(g) + 5H_2O(\ell) \rightarrow 2NaHSO_4(aq) + 8HCl(aq)$$

If 42.5 g of sodium thiosulfate and 175 g of chlorine gas react with excess water, which is the limiting reactant?

38. Acrylonitrile, $C_3H_3N(g)$, is prepared by the reaction of propylene, $C_3H_6(g)$, with nitric oxide, $NO(g)$.

$$4C_3H_6(g) + 6NO(g) \rightarrow 4C_3H_3N(g) + 6H_2O(g) + N_2(g)$$

If 126 g of propylene reacts with 175 g of nitric oxide, which is the limiting reactant?

39. Insoluble silver carbonate, $Ag_2CO_3(s)$, forms in the following balanced chemical reaction:

$$2AgNO_3(aq) + K_2CO_3(aq) \rightarrow Ag_2CO_3(s) + 2KNO_3(aq)$$

What mass of silver nitrate, $AgNO_3(aq)$, reacts with 25.0 g of potassium carbonate, $K_2CO_3(aq)$, if there is at least 5.5 g of silver nitrate in excess?

Learning Check

7. Explain what is meant by the term "stoichiometric amount."

8. Identify the limiting reactant and excess reactant in each situation. Describe any assumptions you made.

- **a.** A pilot flame flickers in a gas fireplace.
- **b.** Vinegar is used to remove deposits in a kettle.
- **c.** A peeled potato turns brown while sitting on a kitchen counter.

9. Four slices of toast, four slices of turkey, two lettuce leaves, and one slice of tomato are available to make turkey sandwiches. Based on **Figure 7.1**, which ingredient is the limiting ingredient?

10. Is the limiting reactant always the compound that is present in the smaller amount? Explain your answer.

11. Why are reactants present in excess amounts not considered when determining the product yield by stoichiometric calculations?

12. When a small quantity of phosphorus, $P_4(s)$, reacts with oxygen gas in open air, which reactant do you think is in excess? Explain your answer.

Using the Limiting Reactant to Find the Amount of Product

Identifying the limiting reactant is crucial for predicting the amount of product that is formed in a chemical reaction, as shown in the following Sample Problem.

Sample Problem

Stoichiometry Using a Limiting Reactant

Thermite Reaction

Problem

The thermite reaction, shown on the right, is a reaction of powdered aluminum with iron(III) oxide, $Fe_2O_3(s)$. This reaction produces so much heat that the iron formed is actually molten (liquid). The balanced chemical equation is

$$2Al(s) + Fe_2O_3(s) \longrightarrow Al_2O_3(s) + 2Fe(\ell)$$

If 113.00 g of aluminum powder is mixed with 279.50 g of iron(III) oxide, what mass of molten iron forms?

What Is Required?

You need to find the mass of molten iron that forms.

What Is Given?

You know the balanced chemical equation:

$$2Al(s) + Fe_2O_3(s) \longrightarrow Al_2O_3(s) + 2Fe(\ell)$$

You know the mass of aluminum powder: 113.00 g

You know the mass of iron(III) oxide: 279.50 g

Plan Your Strategy	Act on Your Strategy
Calculate the molar masses, M, of aluminum, iron(III) oxide, and iron.	$M_{Al} = 26.98$ g/mol $M_{Fe_2O_3} = 2M_{Fe} + 3M_O$ $= 2(55.85\text{ g/mol}) + 3(16.00\text{ g/mol})$ $= 159.70$ g/mol $M_{Fe} = 55.85$ g/mol
Convert the masses of aluminum and iron(III) oxide into amounts (in moles) using the equation $n = \frac{m}{M}$.	$n_{Al} = \frac{m_{Al}}{M_{Al}} = \frac{113.00\ \cancel{g}}{26.98\ \cancel{g}/\text{mol}} = 4.18829\text{ mol Al}$ $n_{Fe_2O_3} = \frac{m_{Fe_2O_3}}{M_{Fe_2O_3}} = \frac{279.50\ \cancel{g}}{159.70\ \cancel{g}/\text{mol}} = 1.75016\text{ mol }Fe_2O_3$
Calculate the amount of iron that forms by the given amount of aluminum and the given amount of iron(III) oxide.	$n_{Fe} = 4.18829\ \cancel{\text{mol Al}} \times \frac{2\text{ mol Fe}}{2\ \cancel{\text{mol Al}}} = 4.18829\text{ mol Fe(s)}$ $n_{Fe} = 1.75016\ \cancel{\text{mol }Fe_2O_3} \times \frac{2\text{ mol Fe}}{1\ \cancel{\text{mol }Fe_2O_3}} = 3.50032\text{ mol Fe(s)}$
Compare the amounts of iron that form by aluminum and iron(III) oxide to determine the limiting reactant.	Iron(III) oxide produces less iron than aluminum does. Therefore, the limiting reactant is iron(III) oxide.
Determine the mass of iron that forms using $m = n \times M$ and the amount of iron that the limiting reactant forms.	$m = n \times M$ $= 3.50\ \cancel{\text{mol}} \times 55.85\text{ g/}\cancel{\text{mol}}$ $= 195.49$ g Fe Therefore, 195.49 g of molten iron is formed.

Check Your Solution

The amount in moles of iron(III) oxide is less than half the amount of aluminum. The mole ratio is 2 mol of aluminum to 1 mol of iron(III) oxide. Iron(III) oxide is the limiting reactant.

Practice Problems

40. The formation of water is represented by the following equation:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

a. What is the limiting reactant if 4 mol of oxygen reacts with 16 mol of hydrogen?

b. What amount (in moles) of water is produced in this reaction?

41. Silver nitrate, $AgNO_3(aq)$, reacts with iron(III) chloride, $FeCl_3(aq)$, to produce silver chloride, $AgCl(s)$, and iron(III) nitrate, $Fe(NO_3)_3(aq)$.

$$3AgNO_3(aq) + FeCl_3(aq) \rightarrow 3AgCl(s) + Fe(NO_3)_3(aq)$$

a. If a solution containing 18.00 g of silver nitrate is mixed with a solution containing 32.4 g of iron(III) chloride, which is the limiting reactant?

b. What amount in moles of iron(III) nitrate is produced in this reaction?

42. Barium sulfate, $BaSO_4(s)$, forms in the following reaction:

$$Ba(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaNO_3(aq)$$

If 75.00 g of barium nitrate, $Ba(NO_3)_2(aq)$, reacts with 100.00 g of sodium sulfate, $Na_2SO_4(aq)$, what mass of barium sulfate is produced?

43. Zinc oxide, $ZnO(s)$, is formed by the reaction of zinc sulfide, $ZnS(s)$, with oxygen.

$$2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$$

If 16.7 g of zinc sulfide reacts with 6.70 g of oxygen, what mass of zinc oxide is produced?

44. The following balanced chemical equation represents the reaction of calcium carbonate, $CaCO_3(s)$, with hydrochloric acid:

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(\ell)$$

If 155 g of calcium carbonate reacts with 245 g of hydrochloric acid, what mass of calcium chloride, $CaCl_2(s)$, is produced?

45. The reaction of aluminum hydroxide, $Al(OH)_3(aq)$, with hydrochloric acid produces water and aluminum chloride, $AlCl_3(s)$.

$$3HCl(aq) + Al(OH)_3(aq) \rightarrow 3H_2O(\ell) + AlCl_3(s)$$

What mass of aluminum chloride is produced when 8.0 g of hydrochloric acid reacts with an equal mass of aluminum hydroxide?

46. The reaction between solid white phosphorus, $P_4(s)$, and oxygen gas produces solid tetraphosphorus decoxide, $P_4O_{10}(s)$. Determine the mass of tetraphosphorus decoxide that is formed when 25.0 g of solid white phosphorus and 50.0 g of oxygen are combined.

47. A solution containing 14.0 g of silver nitrate, $AgNO_3(aq)$, is added to a solution containing 4.83 g of calcium chloride, $CaCl_2(aq)$. Find the mass of silver chloride, $AgCl(s)$, produced.

48. The reaction between solid sodium and iron(III) oxide, $Fe_2O_3(s)$, is one in a series of reactions that occurs when an automobile air bag inflates.

$$6Na(s) + Fe_2O_3(s) \rightarrow 3Na_2O(s) + 2Fe(s)$$

If 100.0 g of solid sodium and 100.0 g of iron(III) oxide are used in this reaction, what mass of solid iron will be produced?

49. Manganese(III) fluoride, $MnF_3(s)$, is formed by the reaction of manganese(III) iodide, $MnI_2(s)$, with fluorine gas.

$$2MnI_2(s) + 13F_2(g) \rightarrow 2MnF_3(s) + 4IF_5(\ell)$$

a. If 1.23 g of manganese(III) iodide reacts with 25.0 g of fluorine, what mass of manganese(III) fluoride is produced?

b. Which reactant is in excess? How much of this reactant remains at the end of the reaction?

50. Silver nitrate, $AgNO_3(aq)$, reacts with calcium chloride, $CaCl_2(aq)$, in the following reaction:

$$2AgNO_3(aq) + CaCl_2(aq) \rightarrow 2AgCl(s) + Ca(NO_3)_2(aq)$$

There are 7 mol of each reactant present.

a. What is the mass of the excess reactant?

b. What is the mass of the limiting reactant?

c. What are the masses of each product that forms?

Applications of Stoichiometry and Limiting Reactants

Stoichiometry, chemical reactions, and limiting reactants are not topics that are relevant only in chemistry class or in the laboratory. You benefit from stoichiometry in your daily life, although you might not realize it. The photographs in **Figure 7.8** show some examples of quantitative chemistry in everyday applications. The activity below also highlights the importance of quantities in chemical reactions in our society.

Figure 7.8 Many processes in the home, workplace, and environment involve the use of chemical quantities and calculations. For example, concentrated herbicides **(A)** must be properly diluted before they are applied to invasive species. Hairdressers **(B)** mix chemicals to colour, straighten, and curl hair.

Activity 7.3 Stoichiometric Applications

Processes in the home and in the workplace often involve the use of chemical quantities and calculations. When you mix cleaning solutions in your home, you often mix them in required proportions according to instructions on the product labels. These proportions are determined by chemists and are designed to give the best results. Pharmacists and other medical professionals must mix medication doses, such as chemotherapy, using stoichiometry to obtain a mixture that achieves the desired results without harming patients. Gardeners, farmers, and nursery workers often mix fungicides, pesticides, herbicides, and fertilizers with water or other ingredients to achieve the correct proportions. If these products are not mixed correctly, the plants might die and damage to the surrounding environment can occur.

Procedure

1. Choose one of the following products that involve the use of stoichiometry and limiting and excess reactants.
   - a specific type of pesticide, herbicide, or fungicide (organic or synthetic) that is used in home gardens or in commercial operations
   - a pharmaceutical product (either an over-the-counter medication or a prescribed medication)
   - a household cleaning solution (organic or synthetic)
   - a consumer product, such as hair colouring, hair relaxer, or permanent wave mixture
   - a product of your choice (approved by your teacher)
2. Use the Internet, product instruction sheets, pharmaceutical inserts, or other reliable resources to research information about your topic.

Questions

1. Answer the following questions as you complete your research:
   a. What is the purpose of your product?
   b. What chemical quantities or calculations are required to ensure safe use of your product?
   c. What are the possible consequences if your chosen product is not mixed correctly?
   d. When your product is being applied or used, what are the limiting and excess reactants?
2. Prepare a short presentation of your findings to share with the class. Consider questions that your classmates might ask about the topic as you prepare your presentation.

Limiting Reactants and Product Formed

In this section, you were introduced to the concept of the limiting reactant in a chemical reaction. You learned that once you have identified the limiting reactant, you can use stoichiometric calculations to predict how much product will be formed in a chemical reaction. However, sometimes the amount of product that is actually formed is quite different from the amount you predicted. In the next section, you will learn why.

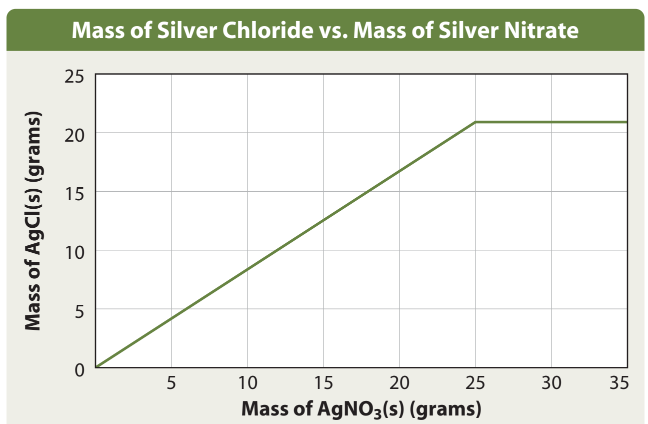
Section 7.2 REVIEW

Section Summary

- A limiting reactant is a reactant that is completely consumed during a chemical reaction, and therefore limits or stops the reaction. Reactants that remain after the reaction stops are called excess reactants.
- To identify the limiting reactant, the amount of product that is produced from each reactant is determined. Then the amounts from both reactants are compared to determine which reactant produces the smaller amount of product.
- Determining the limiting reactant is necessary for all stoichiometric calculations that are used to determine the amount of product that forms.
- In chemical processes, limiting and excess reactants must be managed to ensure that the reactants produce the products safely and efficiently.

Review Questions

1. K/U Calcium reacts with water. If a small piece is dropped into a beaker of water, which reactant is in excess during this reaction?
2. T/I If 47.2 mol of lead(II) oxide, PbO(s), reacts with 6 mol of oxygen according to the equation below, which is the limiting reactant?
$$6PbO(s) + O_2(g) \rightarrow 2Pb_3O_4(g)$$
3. T/I If 72.15 g of pentane, $C_5H_{12}(g)$, reacts with 6.9 mol of oxygen, according to the equation below, which is the limiting reactant?
$$C_5H_{12}(g) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(g)$$
4. T/I In an experiment, 57.4 g of iron(III) chloride in solution reacts with 45.3 g of sodium hydroxide in solution, as shown below.
$$FeCl_3(aq) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + 3NaCl(aq)$$
   a. Which reactant is the limiting reactant?
   b. How much of the excess reactant remains after the reaction?
   c. How much of each product forms?
5. T/I Solid sodium metal reacts with chlorine gas to form table salt.
$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$
   What is the minimum mass of chlorine gas that is required to consume 2.25 g of solid sodium?
6. K/U Define the term "limiting reactant," and give a specific example from your own experience.
7. C Using a numbered list of steps, explain the process of identifying the limiting reactant in a chemical reaction.
8. C A candle is burning at the bottom of a container. The container is then covered until the candle is almost extinguished. When the cover is removed, the candle flame recovers and burns normally again. Use stoichiometry and the concept of the limiting reactant to explain your observations.
9. T/I Copper reacts with nitric acid, $HNO_3(aq)$, as follows:
$$3Cu(s) + 8HNO_3(aq) \rightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(\ell)$$
   What mass of nitrogen monoxide, NO(g), is produced when 50.0 g of copper reacts with 150.0 g of nitric acid?
10. T/I The following chemical equation represents the reaction of silver nitrate, $AgNO_3(aq)$, with sodium chloride:
$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$
   Different amounts of silver nitrate are added to a fixed amount of sodium chloride. For each mass of silver nitrate, the mass of sliver chloride, AgCl(s), precipitate is determined and plotted on the graph below.



   a. Why does the graph level off after 25 g of silver nitrate is added to the sodium chloride?
   b. What amount in moles of sodium chloride is the fixed amount?
11. A You pour household vinegar on mineral deposits on a kitchen faucet. Some of the deposits wash away. You pour more vinegar on the deposits and they all wash way. Explain what occurred using the terms "limiting reactant" and "excess reactant."