The Concept of Limiting Reactant

Suppose you have a job in a sandwich shop. One very popular sandwich is always made as follows:

$$2 \text{ slices bread} + 3 \text{ slices meat} + 1 \text{ slice cheese} \rightarrow 1 \text{ sandwich}$$

Assume that you come to work one day and find the following quantities of ingredients:

8 slices bread   9 slices meat   5 slices cheese

How many sandwiches can you make? What will be left over?

To solve this problem, see how many sandwiches we can make with each ingredient:

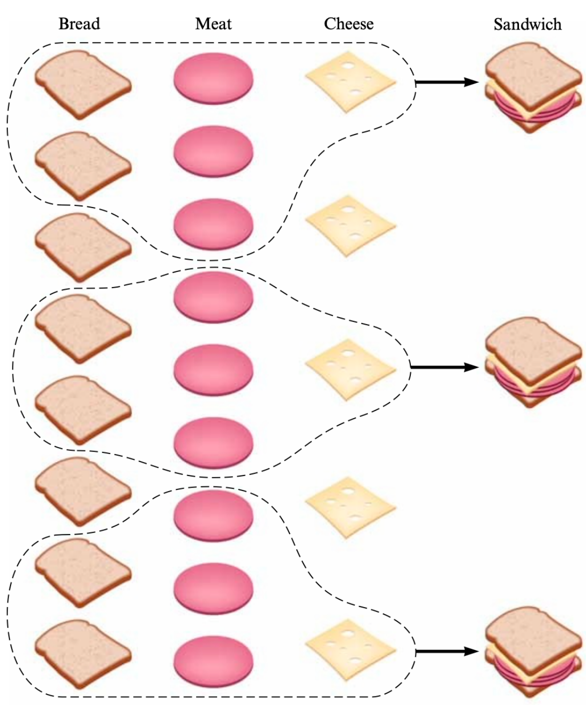
Bread: $$8 \text{ slices bread} \times \frac{1 \text{ sandwich}}{2 \text{ slices bread}} = 4 \text{ sandwiches}$$

Meat: $$9 \text{ slices meat} \times \frac{1 \text{ sandwich}}{3 \text{ slices meat}} = 3 \text{ sandwiches}$$

Cheese: $$5 \text{ slices cheese} \times \frac{1 \text{ sandwich}}{1 \text{ slice cheese}} = 5 \text{ sandwiches}$$

How many sandwiches can you make? The answer is three. Once you run out of meat, you must stop making sandwiches. Meat is the limiting ingredient.

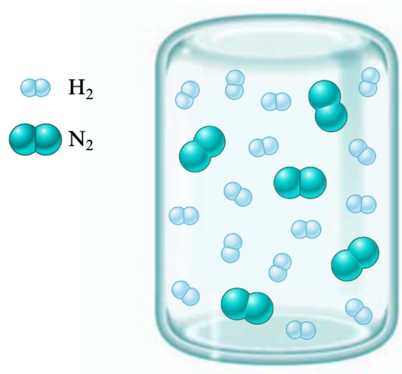
What will be left over? Making three sandwiches requires six slices of bread and three slices of cheese. This means you will have two slices of bread and two slices of cheese left over.



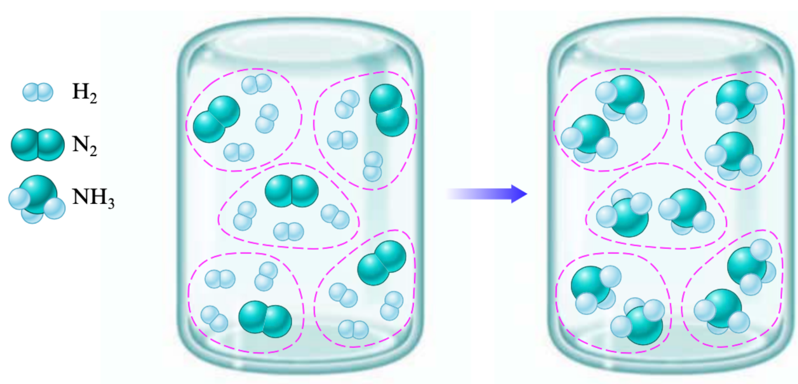
When molecules react with each other to form products, considerations very similar to those involved in making sandwiches arise. We can illustrate this with the following reaction:

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

Consider the following container of $N_2(g)$ and $H_2(g)$:



What will this container look like after the reaction proceeds to completion? To answer this question, remember that each N_2 requires 3 H_2 molecules to form $2NH_3$. To make this clear, we can circle groups of reactants:



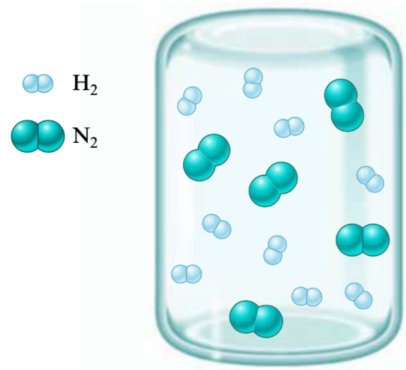
Before the reaction
After the reaction

In this case, the mixture contained exactly the correct number of molecules needed to form NH_3 with nothing left over. That is, the ratio of the number of H_2 molecules to N_2 molecules was

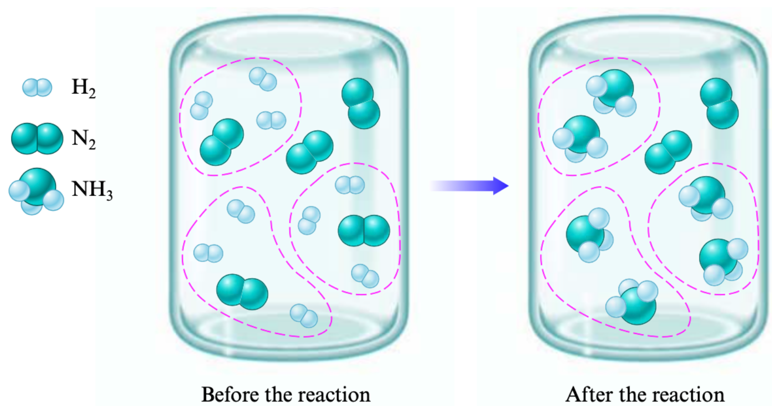
$$\frac{15H_2}{5N_2} = \frac{3H_2}{1N_2}$$

This ratio exactly matches the coefficients in the balanced equation. This type of mixture is called a **stoichiometric mixture** — one that contains exactly the correct amounts of reactants so that there are no leftover reactants once the reaction is complete.

Now consider another container of $N_2(g)$ and $H_2(g)$:



What will this container look like after the reaction proceeds to completion? Remember that each N_2 requires 3 H_2. Circling groups of reactants and products, we have:



In this case, the H_2 molecules are used up before the N_2 molecules are consumed. In this situation, the amount of hydrogen limits the amount of product (ammonia) that can form — hydrogen is the limiting reactant.

Another way of representing this reaction would be to use a table. Suppose we start out with 5 molecules of N_2 and 9 molecules of H_2. We can organize our data as shown below:

	N_2	$+$	$3H_2$	$\rightarrow$	$2NH_3$
Before	5		9		0
Change	–?		–?		+?
After	?		?		?

Assuming the reaction goes to completion, there are two possibilities: either N_2 or H_2 must be zero in the *After* row.

Possibility I: H_2 runs out first:

	N_2	$+$	$3H_2$	$\rightarrow$	$2NH_3$
Before	5		9		0
Change	–?		–9		+?
After	?		0		?

Possibility II: N_2 runs out first:

	N_2	$+$	$3H_2$	$\rightarrow$	$2NH_3$
Before	5		9		0
Change	–5		–?		+?
After	0		?		?

For Possibility I, 9 molecules of H_2 are consumed. According to the balanced equation, 1 N_2 molecule is consumed for every 3 H_2 molecules. Thus, 3 molecules of N_2 must be consumed along with the 9 molecules of H_2.

Similarly, 2 molecules of NH_3 are produced for every 3 molecules of H_2 that are consumed. Thus, 6 molecules of NH_3 must be produced when the 9 molecules of H_2 are consumed.

Possibility I: H_2 runs out first:

	N_2	$+$	$3H_2$	$\rightarrow$	$2NH_3$
Before	5		9		0
Change	–3		–9		+6
After	2		0		6

We can use similar reasoning to complete the table for Possibility II.

Possibility II: N_2 runs out first:

	N_2	$+$	$3H_2$	$\rightarrow$	$2NH_3$
Before	5		9		0
Change	–5		–15		+10
After	0		–6		10

We can see that N_2 is not limiting by examining the results of Possibility II. For all of the N_2 to react, we would require 6 more molecules of H_2 than we actually have.

Notice that Possibility I conveys all of the information we saw in the pictures of the reaction container. We started with 5 molecules of N_2 and 9 molecules of H_2, and after the reaction is complete we are left with 2 molecules of N_2 and 6 molecules of NH_3.

Using a table like this is convenient in that all of the information is conveyed in one place.

Summary

To determine how much product can be formed from a given mixture of reactants, we have to look for the reactant that is limiting — the one that runs out first and thus limits the amount of product that can form.

The reactant that runs out first and thus limits the amount of products that can form is called the **limiting reactant**.

Determining the Limiting Reactant

There are two different methods for determining which reactant in a chemical reaction is limiting. The one that we will use is as follows:

1. Determine the number of moles of each reactant.

2. Determine the amount of product that each reactant *could* produce if fully consumed.

3. The limiting reactant is the reactant which produces the least amount of product.

Example 1
Disulfur dichloride is used to vulcanize rubber, a process that makes rubber harder, stronger, and less likely to become soft when hot or brittle when cold. In the production of disulfur dichloride, molten sulfur reacts with chlorine gas according to the equation:

$$S_8(l) + 4Cl_2(g) \rightarrow 4S_2Cl_2(l)$$

If $200.0\ g$ of sulfur reacts with $100.0\ g$ of chlorine, which is the limiting reactant?

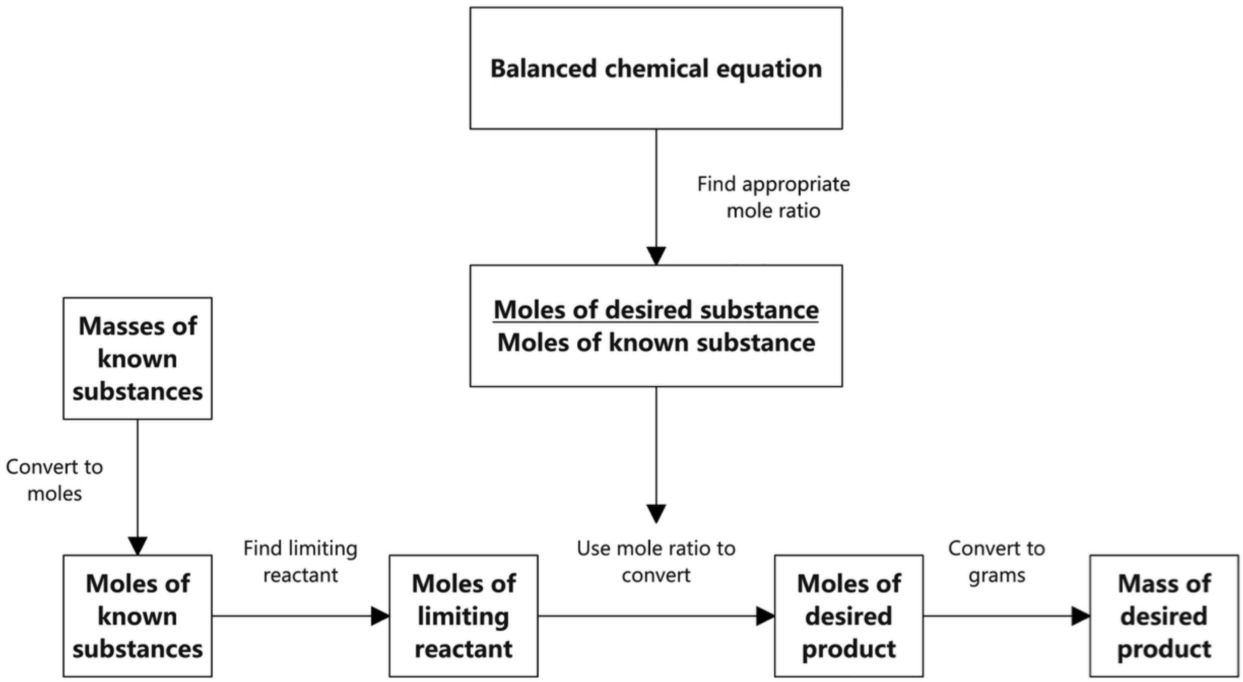
Example 2

The reaction between solid white phosphorus and oxygen gas produces solid tetraphosphorus decoxide (P_4O_{10}). This compound is often called diphosphorus pentoxide because its empirical formula is P_2O_5

a) Determine the mass of tetraphosphorus decoxide formed if $25.0\ g$ of phosphorus (P_4) and $50.0\ g$ of oxygen gas are combined.

b) How much of the excess reactant remains after the reaction stops?

Problem Solving Strategy
Solving a Stoichiometry Problem Involving Masses of Reactants and Products
1. Write the balanced equation for the reaction. 2. Convert the known masses of substances to moles. 3. Determine which reactant is limiting. 4. Using the amount of the limiting reactant and the appropriate mole ratios, determine the number of moles of the desired product. 5. Convert from moles to grams, using the molar mass.



Stoichiometry Worksheet #5

1. The reaction between solid sodium and iron (III) oxide is one in a series of reactions that inflates an automobile airbag.

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

If $100.0\ g\ Na$ and $100.0\ g\ Fe_2O_3$ are used in this reaction, determine

a) the limiting reactant.

b) the reactant in excess.

c) the mass of solid iron produced.

d) the mass of excess reactant that remains after the reaction is complete.

2. Photosynthesis reactions in green plants use carbon dioxide and water to produce glucose ($C_6H_{12}O_6$) and oxygen. Write the balanced chemical equation for the reaction. If a plant has $88.0\ g$ carbon dioxide and $64.0\ g$ water available for photosynthesis, determine

a) the limiting reactant.

b) the excess reactant and the mass in excess.

c) the mass of glucose produced.

3. This reaction takes place in a nickel-iron battery.

$$Fe(s)+2NiO(OH)(s)+2H_2O(l)\rightarrow Fe(OH)_2(s)+2Ni(OH)_2(aq)$$

Determine the number of moles of iron(II) hydroxide ($Fe(OH)_2$) produced if $5.00\ mol\ Fe$ and $8.00\ mol\ NiO(OH)$ react.

4. An alkaline battery produces electrical energy according to this equation.

$$Zn(s)+2MnO_2(s)+H_2O\rightarrow Zn(OH)_2(s)+Mn_2O_3(s)$$

a) Determine the limiting reactant if $25.0\ g\ Zn$ and $30.0\ g\ MnO_2$ are used.

b) Determine the mass of $Zn(OH)_2$ produced.

5. Consider the reaction below:

$$3NH_4NO_3 + Na_3PO_4 \rightarrow (NH_4)_3PO_4 + 3NaNO_3$$

a) Determine the limiting reactant if $30\ g\ NH_4NO_3$ and $50\ g\ Na_3PO_4$ are used.

b) Determine the mass of $(NH_4)_3PO_4$ that is produced.

c) Determine the mass of $NaNO_3$ that is produced.

d) Determine the mass of excess reactant that remains after the reaction is complete.

6. Consider the reaction below:

$$3CaCO_3 + 2FePO_4 \rightarrow Ca_3(PO_4)_2 + Fe_2(CO_3)_3$$

a) Determine the limiting reactant if $100\ g\ CaCO_3$ and $45\ g\ FePO_4$ are used.

b) Determine the mass of $Ca_3(PO_4)_2$ that is produced.

c) Determine the mass of $Fe_2(CO_3)_3$ that is produced.

d) Determine the mass of excess reactant that remains after the reaction is complete.