B.4 LIMITING REACTANTS

Biochemical reactions in your body convert the fats, carbohydrates, and—under extreme conditions—proteins in the food you eat into energy. These biochemical reactions, like all chemical reactions, require the presence of a complete set of reactants to produce the desired product. Furthermore, the amount of product produced by a chemical reaction depends upon the amounts of reactants present.

To understand how the amounts of reactants determine how much product can be made by a chemical reaction, think about baking a cake. Consider this cake recipe:

2 cups flour	$1\frac{1}{2}$ tablespoons baking powder
2 eggs	1 cup water
1 cup sugar	1/3 cup oil

The proper combination of these quantities (and some thermal energy) will produce one cake. Suppose you have 14 cups flour, 4 eggs, 9 cups sugar, 15 tablespoons baking powder, 10 cups water, and 3–1/3 cups oil. How many cakes can be baked?

Well, 14 cups of flour is enough for 7 cakes (2 cups flour per cake). And there is enough sugar for 9 cakes (1 cup sugar per cake). The supplies of baking powder, water, and oil are sufficient for 10 cakes (confirm this with the recipe). Yet it is not possible to make 10, 9, or even 7 cakes with the available ingredients.

Why? Because only 4 eggs are available—enough just for 2 cakes. The supply of eggs limits the number of cakes that can be made. The excess quantities of other ingredients (flour, sugar, baking powder, water, and oil) remain unused. If more cakes are desired, more eggs (along with required amounts of the other ingredients) will be needed.

In chemical terminology, the eggs in this cake-making example represent the limiting reactant (or limiting reagent). The limiting reactant is the starting material (reactant) that is used up entirely when a chemical reaction occurs. This material limits how much (or how little) product can be formed.

Limiting reactants were first introduced in Unit 4, page 288.

In chemical reactions, just as in recipes, materials react in certain fixed ratios. These relative amounts are indicated in chemical equations by the coefficients. Consider the equation for the oxidation ("burning") of glucose. First, the equation can be interpreted in terms of one glucose molecule:

$$\underset{\text{1 Glucose molecule}}{C_6H_{12}O_6} + \underset{\text{6 Oxygen molecules}}{6\,O_2} \longrightarrow \underset{\text{6 Carbon dioxide molecules}}{6\,CO_2} + \underset{\text{6 Water molecules}}{6\,H_2O} + \text{Energy}$$

Suppose you have available 5 glucose molecules to react with 60 oxygen molecules. Which substance will be the limiting reactant in this reaction? From the equation, you can see that one glucose molecule reacts with 6 oxygen molecules. That means that the 5 glucose molecules require 30 oxygen molecules to react completely. To use up all of the 60 oxygen molecules,

MODELING MATTER

LIMITING REACTANTS

1. Consider the cake-making example that was just discussed. This time, assume you have 26 eggs and the quantities of the other ingredients specified previously.
   a. Which ingredient now limits the total number of cakes you can make? (In other words, what is the new limiting reactant?)
   b. How many cakes can be made if the other ingredients are present in the same quantities as in the original example?
   c. When the limiting reactant is used up, how much of each other ingredient will be left over?
2. A restaurant prepares carry-out lunches. Each completed lunch includes 1 sandwich, 3 cookies, 2 paper napkins, 1 carton of milk, and 1 box. The current inventory is 60 sandwiches, 102 cookies, 38 napkins, 41 cartons of milk, and 66 boxes.
   a. As carryout lunches are prepared, which item will be used up first?
   b. Which item is the limiting reactant?
   c. How many complete carryout lunches can be assembled from this inventory?
3. Now it is your turn to write a limiting reactant problem. Think about a limiting reactant problem that you encounter in your daily life. First, decide what item you are trying to create. Then, write down all of the necessary "reactants" you need. Finally, identify the limiting "reactant" and how many of the other "reactants" will be left over.

however, requires 10 glucose molecules. Which of those two scenarios is actually possible in this reaction? In other words, which reactant—oxygen or glucose—will be used completely in this reaction?

First, consider glucose molecules. The 5 glucose molecules require 30 oxygen molecules, as noted above. Since 60 oxygen molecules are available, all of the glucose can react, with some oxygen "left over." On the other hand, consider the oxygen molecules. To react completely, the 60 oxygen molecules require 10 glucose molecules—but only 5 glucose molecules are available in the reaction. Thus, through either line of reasoning, glucose must be the limiting reactant. Since the reaction stops once the 5 glucose molecules react with 30 oxygen molecules, 30 oxygen molecules will remain unreacted ("excess") at the end of the reaction. Additional glucose would be needed for the reaction to continue.

The idea of limiting reactants applies equally well to living systems. A shortage of a key nutrient or reactant can severely affect the growth or health of plants and animals. In many biochemical processes, a product from one reaction becomes a reactant for other reactions. If a reaction stops due to a shortage of one substance (the limiting reactant), all reactions following that step will also shut down.

MODELING MATTER

LIMITING REACTANTS

This activity gives students practice in predicting the amounts of products obtained when one reactant is limited. Although none of the systems is "chemical," the calculations correspond closely to those required in chemical systems. This early practice is deliberately limited to concrete, macroscopic systems, so that the central idea will be easier to understand. If students have difficulty with the concept, suggest that they calculate how much product is possible for each reactant and compare the results.

Answers

1. a. Flour is the limiting reactant.
   b. seven cakes.
   c. 12 eggs, 2 c sugar, 4.5 T baking soda, 3 c water, 1 c oil.
2. a. Napkins are used up first.
   b. napkins
   c. 19 lunch boxes are possible.
3. Student answers. Products, such as a simple machine, birdhouse, or first aid kit would work well.

DEMONSTRATION

This demonstration provides a chemical example of the limiting reactant concept, involving easily observed chemical changes. Use a shield during this demonstration. Take care that no flames are used when the balloons are emptied.

Materials

8 culture tubes
8 round balloons (inflated diameter 4 inches)
50 mL 3 M hydrochloric acid
55 cm magnesium ribbon

MODELING MATTER

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Demonstration tips

Fill the tubes with the listed volumes of hydrochloric acid, clearly label them by number, and place them in test tube racks. Fold each piece of magnesium ribbon so it will fit inside an uninflated balloon.

Part A: Constant amount of HCl, variable amount of Mg

Tube 1: 5 mL 3 M HCl + 2.5 cm Mg ribbon (3 M HCl: 12.5 mL conc. HCl/50 mL solution)
Tube 2: 5 mL 3 M HCl + 5.0 cm Mg ribbon
Tube 3: 5 mL 3 M HCl + 10.0 cm Mg ribbon
Tube 4: 5 mL 3 M HCl + 15.0 cm Mg ribbon