Chapter

5

Quantities in Chemical Equations

One of the most useful applications of chemistry is the synthesis of new substances that benefit society. New medicines are developed every year, and new materials for clothing, sports equipment, and cleaning products are advertised daily.

That is why the discovery of new and better ways of synthesizing existing chemicals is so exciting. New procedures often follow the development of new technologies and always require an understanding of both qualitative and quantitative aspects of chemical reactions. Industries are particularly interested in the costs of their chemical processes, and quantitative analysis is key to a company's profitability.

Let's take the example of the production of soda ash (sodium carbonate, $Na_2CO_{3(s)}$). You may have used sodium carbonate as a cleaner, commonly called washing soda. It was first extracted from plant ashes and used to make soap. In 1775, as the demand for soap exceeded the supply of sodium carbonate, the French Academy of Science offered a prize for the development of an industrial method of making sodium carbonate from common substances. As a result of this offer, the LeBlanc process was developed. To make sodium carbonate using the LeBlanc process, sodium chloride and sulfuric acid are heated; then limestone and coal are added and heated again, to a high temperature. Quantitatively, the LeBlanc process was inefficient. It required burning a lot of coal, which was expensive and generated hydrogen chloride, a severe air pollutant. One of the byproducts was an insoluble residue that had no commercial value. In other words, a great deal of resources and energy was put into the reaction, and only a small proportion of the materials was recovered as a useful product.

It was not until 1867—after approximately a hundred years of using the LeBlanc process—that a new process was developed for the production of sodium carbonate. You will learn more about this Solvay process later in the chapter (**Figure 1**); you will also learn how to calculate amounts of substances taking part in chemical reactions and how science and technology are linked in the search for better products and processes.

In this chapter, you will be able to

- balance chemical and nuclear equations;
- solve problems involving quantity in moles, mass, or molecules of any reactant or product in a chemical equation;
- determine the limiting reagent in a chemical reaction and solve problems involving percentage yield;
- analyze experimental results to compare actual yield and percentage yield and evaluate sources of experimental error;
- give examples of the application of chemical quantities and calculations;
- identify careers related to the study of chemistry.

Reflect on your Learning

1. (a) Based on what you learned in previous chapters, summarize all of the qualitative and quantitative information that is communicated in a balanced chemical equation.
   (b) Of all the different types of information in your summary, can you suggest one that is less important than the others? Justify your answer.
2. In what way does an understanding of the quantities of reactants and products in chemical reactions increase profitability in an industrial process?
3. What different strategies and equipment have you used in quantitative applications, at home or at school (e.g., measuring spoon, centigram balance, thermometer)? Using a scale of 1 to 10, rank each strategy or piece of equipment for accuracy of measurement.

Throughout this chapter, note any changes in your ideas as you learn new concepts and develop your skills.

Try This **Activity**

How Much Gas?

When sodium hydrogen carbonate, $NaHCO_{3(s)}$, commonly called baking soda, reacts with an acid such as acetic acid (in vinegar), carbon dioxide is produced. In this activity, you will compare the amounts of gas produced when a fixed amount of sodium hydrogen carbonate is mixed with increasing amounts of acetic acid.

Materials: eye protection, sodium hydrogen carbonate (100 mL, approximately 5 tbsp.), 300 mL vinegar (5% acetic acid), 3 small, sealable plastic bags, graduated cylinder, measuring spoon

Acetic acid in vinegar may irritate the eyes. If acetic acid comes in contact with the eye, immediately wash the eye under cold running water.

- Using the measuring spoon, carefully place 15 mL (approximately 3 tsp.) of sodium hydrogen carbonate into a bottom corner of one bag. Fold the corner upward and tape it in place so that the solid is kept out of contact with other ingredients to be added to the bag.
- Carefully pour 30 mL of vinegar into the other bottom corner of the bag, keeping it out of contact with the solid.
- Flatten and press the bag gently to remove as much air as possible, and seal the bag.
- Remove the tape and shake the bag to allow the sodium hydrogen carbonate to mix well with the vinegar.
- Allow the reaction to continue until no more bubbles are produced. Keep the bag sealed for later observations.
- Repeat the procedure with another bag, using the same amount of sodium hydrogen carbonate and increasing the amount of vinegar to 60 mL.
- Repeat, increasing the amount of vinegar to 120 mL.
  (a) Record the *relative* volumes of gas in the three sealed bags. Is there evidence that the amount of product formed is related to the amount of reactants used?
  (b) Is there evidence that some of the sodium hydrogen carbonate had not completely reacted in one or more of the bags?
- Open each bag and add 15 mL of vinegar to each.
  (c) Is there evidence that a shortage of vinegar was limiting the production of carbon dioxide gas in some bags?
- Add 15 mL of sodium hydrogen carbonate to each bag.
  (d) Is there evidence that a lack of sodium hydrogen carbonate was limiting the production of carbon dioxide gas in some bags?
  (e) When sodium hydrogen carbonate, a bitter-tasting base, is used to make lemon cake, it reacts with the citric acid in the lemon juice to produce bubbles of carbon dioxide. Should the amount of sodium hydrogen carbonate be chosen to limit the production of bubbles, or should it be used in excess amounts? Explain your answer.
  (f) Some recipes give measurements in capacity units (e.g., millilitres or teaspoons of baking soda) while others use mass units (e.g., grams of flour). Explain which of these measurements you think is more accurate.
- Clean up according to instructions from your teacher. Wash your hands.

Figure 1
Soap making was a yearly event undertaken by early Canadian settlers. Waste cooking grease and wood ashes were collected year-round and boiled together in quantities determined by trial and error, with uncertain results. Advances in the industrial production of soaps led to great improvements in personal hygiene and public health.