Section 12.2

Stoichiometric Calculations

Objectives

- **Explain** the sequence of steps used in solving stoichiometric problems.
- **Use** the steps to solve stoichiometric problems.

Suppose a chemist needs to obtain a certain amount of product from a reaction. How much reactant must be used? Or, suppose the chemist wants to know how much product will form if a certain amount of reactant is used. Chemists use stoichiometric calculations to answer these questions.

Using Stoichiometry

Recall that stoichiometry is the study of quantitative relationships between the amounts of reactants used and the amounts of products formed by a chemical reaction. What are the tools needed for stoichiometric calculations? All stoichiometric calculations begin with a balanced chemical equation, which indicates relative amounts of the substances that react and the products that form. Mole ratios based on the balanced chemical equation are also needed. You learned to write mole ratios in Section 12.1. Finally, mass-to-mole conversions similar to those you learned about in Chapter 11 are required.

Stoichiometric mole-to-mole conversion The vigorous reaction between potassium and water is shown in **Figure 12-3**. How can you determine the number of moles of hydrogen produced when 0.0400 mole of potassium is used? Start by writing the balanced chemical equation.

$$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$$

Then, identify the substance that you know and the substance that you need to determine. The given substance is 0.0400 mole of potassium. The unknown is the number of moles of hydrogen. Because the quantity of the given substance is in moles and the unknown substance is to be determined in moles, this problem is a mole-to-mole conversion.

To solve the problem, you need to know how the unknown moles of hydrogen are related to the known moles of potassium. In Section 12.1 you learned to use the balanced chemical equation to write mole ratios that describe mole relationships. Mole ratios are used as conversion factors to convert a known number of moles of one substance to moles of another substance in the same chemical reaction. What mole ratio could be used to convert moles of potassium to moles of hydrogen? In the correct mole ratio, the moles of unknown (H_2) should be the numerator and the moles of known (K) should be the denominator. The correct mole ratio is

$$\frac{1 \text{ mol } H_2}{2 \text{ mol K}}$$

This mole ratio can be used to convert the known number of moles of potassium to a number of moles of hydrogen. Remember that when you use a conversion factor, the units must cancel.

$$\text{moles of known} \times \frac{\text{moles of unknown}}{\text{moles of known}} = \text{moles of unknown}$$

$$0.0400 \cancel{\text{mol K}} \times \frac{1 \text{ mol } H_2}{2 \cancel{\text{mol K}}} = 0.0200 \text{ mol } H_2$$

If you put 0.0400 mol K into water, 0.0200 mol H_2 will be produced. The **How It Works** feature at the end of this chapter shows the importance of mole ratios.

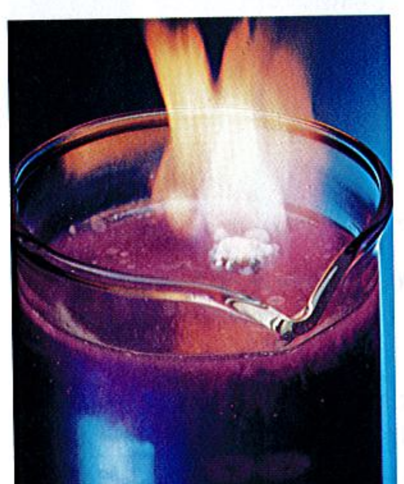

Figure 12-3

Potassium metal reacts vigorously with water, releasing so much heat that the hydrogen gas formed in the reaction catches fire.

EXAMPLE PROBLEM 12-2

Stoichiometric Mole-to-Mole Conversion

One disadvantage of burning propane (C_3H_8) is that carbon dioxide (CO_2) is one of the products. The released carbon dioxide increases the growing concentration of CO_2 in the atmosphere. How many moles of carbon dioxide are produced when 10.0 moles of propane are burned in excess oxygen in a gas grill? $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

1. Analyze the Problem

You are given moles of the reactant propane, and moles of the product carbon dioxide must be found. The balanced chemical equation must be written. Conversion from moles of C_3H_8 to moles of CO_2 is required. The correct mole ratio has moles of unknown substance in the numerator and moles of known substance in the denominator.

Known

moles of propane = 10.0 mol C_3H_8

Unknown

moles of carbon dioxide = ? mol CO_2

2. Solve for the Unknown

Write the balanced chemical equation. Label the known substance and the unknown substance.

	C_3H_8	$+ 5O_2 \rightarrow$	$3CO_2$	$+ 4H_2O$
mol	10.0		30.0	

$\left(\frac{3}{1}\right)$

* $\frac{3}{1}$ is the mole ratio between C_3H_8 and CO_2

3. Evaluate the Answer

The given number of moles has three significant figures. Therefore, the answer must have three digits. The balanced chemical equation indicates that 1 mol C_3H_8 produces 3 mol CO_2. Thus, 10.0 mol C_3H_8 would produce three times as many moles of CO_2, or 30.0 mol.

Math Handbook

Review dimensional analysis in the **Math Handbook** on page 900 of this text.

PRACTICE PROBLEMS

9. Sulfuric acid is formed when sulfur dioxide reacts with oxygen and water. Write the balanced chemical equation for the reaction. If 12.5 mol SO_2 reacts, how many mol H_2SO_4 can be produced? How many mol O_2 is needed?

10. A reaction between methane and sulfur produces carbon disulfide (CS_2), a liquid often used in the production of cellophane.

    ___ $CH_4(g)$ + ___ $S_8(s) \rightarrow$ ___ $CS_2(l)$ + ___ $H_2S(g)$

    a. Balance the equation.

    b. Calculate the mol CS_2 produced when 1.50 mol S_8 is used.

    c. How many mol H_2S is produced?

Practice!

For more practice converting from moles of one substance to moles of another substance in a chemical equation, go to **Supplemental Practice Problems** in Appendix A.

The reaction of sodium and chlorine to form sodium chloride releases a large amount of energy in the form of light and heat. It should not surprise you, then, that a large amount of energy is required to decompose sodium chloride.

Stoichiometric mole-to-mass conversion Now, suppose you know the number of moles of a reactant or product in a reaction and you want to calculate the mass of another product or reactant. This situation is an example of a mole-to-mass conversion.

EXAMPLE PROBLEM 12-3

Stoichiometric Mole-to-Mass Conversion

Determine the mass of sodium chloride or table salt (NaCl) produced when 1.25 moles of chlorine gas reacts vigorously with sodium.

$2Na + Cl_2 \rightarrow 2NaCl$

1. Analyze the Problem

You are given the moles of the reactant Cl_2 and must determine the mass of the product NaCl. You must convert from moles of Cl_2 to moles of NaCl using the mole ratio from the equation. Then, you need to convert moles of NaCl to grams of NaCl using the molar mass as the conversion factor.

Known

moles of chlorine = 1.25 mol Cl_2

Unknown

mass of sodium chloride = ? g NaCl

2. Solve for the Unknown

Write the balanced chemical equation and identify the known and unknown substances.

	2 Na	+ Cl_2	→ 2NaCl
g			146
g/mol			58.44
mol		1.25	2.50

(2/1)

…Cl_2.

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3. Evaluate the Answer

The given number of moles has three significant figures, so the mass of NaCl is correctly stated with three digits. The computations are correct and the unit is as expected.

PRACTICE PROBLEMS

11. Titanium is a transition metal used in many alloys because it is extremely strong and lightweight. Titanium tetrachloride ($TiCl_4$) is extracted from titanium oxide using chlorine and coke (carbon).

$TiO_2(s) + C(s) + 2Cl_2(g) \rightarrow TiCl_4(s) + CO_2(g)$

If you begin with 1.25 mol TiO_2, what mass of Cl_2 gas is needed?

12. Sodium chloride is decomposed into the elements sodium and chlorine by means of electrical energy. How many grams of chlorine gas can be obtained from 2.50 mol NaCl?

Practice! For more practice converting from moles of one substance to mass of another substance in a chemical equation, go to **Supplemental Practice Problems** in Appendix A.

Stoichiometric mass-to-mass conversion If you were preparing to carry out a chemical reaction in the laboratory, you would need to know how much of each reactant to use in order to produce the mass of product you required. Example Problem 12-4 will demonstrate how you can use a measured mass of the known substance, the balanced chemical equation, and mole ratios from the equation to find the mass of the unknown substance. The **CHEMLAB** at the end of this chapter will provide you with laboratory experience determining a mole ratio.

Try at Home LAB

See page 957 in Appendix E for **Baking Soda Stoichiometry**

EXAMPLE PROBLEM 12-4

Stoichiometric Mass-to-Mass Conversion

Ammonium nitrate (NH_4NO_3), an important fertilizer, produces N_2O gas and H_2O when it decomposes. Determine the mass of water produced from the decomposition of 25.0 g of solid ammonium nitrate.

$NH_4NO_3 \rightarrow N_2O + 2H_2O$

1. Analyze the Problem

You are given the mass of the reactant and will need to write the balanced chemical equation. You then must convert from the mass of the reactant to moles of the reactant. You will next use a mole ratio to relate moles of the reactant to moles of the product. Finally, you will use the molar mass to convert from moles of the product to the mass of the product.

Known

mass of ammonium nitrate = 25.0 g NH_4NO_3

Unknown

mass of water = ? g H_2O

2. Solve for the Unknown

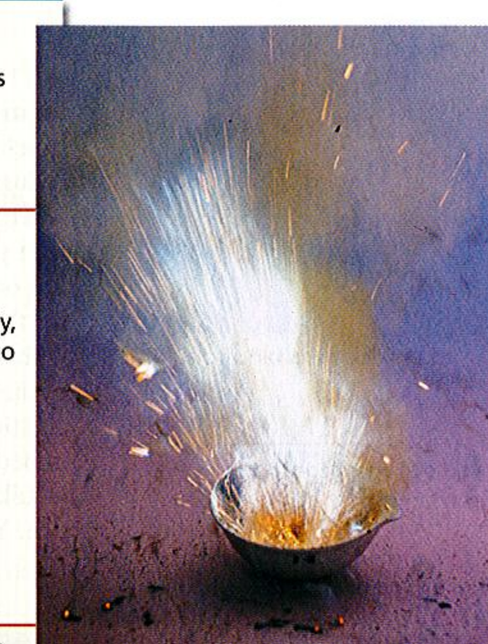
Write the balanced chemical equation for the reaction and identify the known and unknown substances.

	NH_4NO_3	→ N_2O	+ $2H_2O$
g	25.0		11.2
g/mol	80.04		18.02
mol	0.312		0.624

(2/1)

3. Evaluate the Answer

The number of significant figures in the answer, three, is determined by the given moles of ammonium nitrate. The calculations are correct and the unit is appropriate.



The vigorous decomposition of … ests to … owever, … lso widely … ause it … for

Practice!

For more practice converting from mass of one substance to mass of another substance in a chemical equation, go to **Supplemental Practice Problems** in Appendix A.

PRACTICE PROBLEMS

13. One in a series of reactions that inflate air bags in automobiles is the decomposition of sodium azide (NaN_3).

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Determine the mass of N_2 produced if 100.0 g NaN_3 is decomposed.

14. In the formation of acid rain, sulfur dioxide reacts with oxygen and water in the air to form sulfuric acid. Write the balanced chemical equation for the reaction. If 2.50 g SO_2 react with excess oxygen and water, how many grams of H_2SO_4 are produced?

The steps you followed in Example Problem 12-4 are illustrated in **Figure 12-4** and described below it. Use the steps as a guide when you do stoichiometric calculations until you become thoroughly familiar with the procedure. Study **Figure 12-4** as you read.

The specified unit of the given substance determines at what point you will start your calculations. If the amount of the given substance is in moles, step 2 is omitted and step 3, mole-to-mole conversion, becomes the starting point for the calculations. However, if mass is the starting unit, calculations begin with step 2. The end point of the calculation depends upon the specified unit of the unknown substance. If the answer is to be obtained in moles, the calculation is finished with step 3. If the mass of the unknown is to be determined, you must go on to step 4.

Like any other type of problem, stoichiometric calculations require practice. You can begin to practice your skills in the **miniLAB** that follows.

miniLAB

Baking Soda Stoichiometry

Predicting When baking soda is an ingredient in your recipe, its purpose is to make the batter rise and produce a product with a light and fluffy texture. That's because baking soda, or sodium hydrogen carbonate ($NaHCO_3$), decomposes upon heating to form carbon dioxide gas.

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$$

Predict how much sodium carbonate (Na_2CO_3) is produced when baking soda decomposes.

Materials ring stand, ring, clay triangle, crucible, crucible tongs, Bunsen burner, balance, 3.0 g baking soda ($NaHCO_3$)

Procedure

1. Measure the mass of a clean, dry crucible. Add about 3.0 g of $NaHCO_3$ and measure the combined mass of the crucible and $NaHCO_3$. Record both masses in your data table and calculate the mass of the $NaHCO_3$.
2. Use this starting mass of baking soda and the balanced chemical equation to calculate the mass of Na_2CO_3 that will be produced.
3. Set up a ring stand with a ring and clay triangle for heating the crucible.
4. Heat the crucible slowly at first and then with a stronger flame for 7–8 min. Use tongs to remove the hot crucible. Record your observations during the heating.
5. Allow the crucible to cool and then obtain the mass of the crucible and sodium carbonate.

Analysis

1. What were your observations during the heating of the baking soda?
2. How did your calculated mass of sodium carbonate compare with the actual mass you obtained from the experiment? If the two masses are different, suggest reasons for the difference.

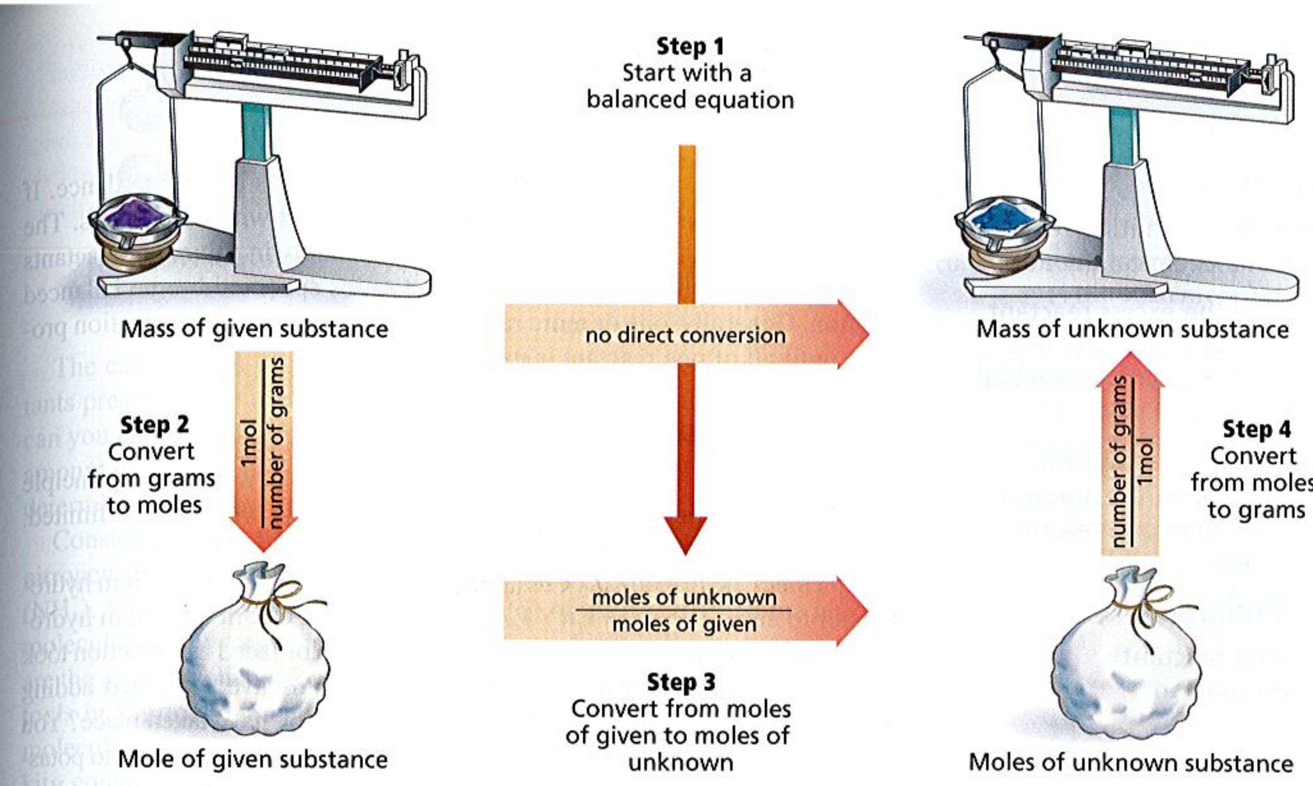


Figure 12-4

Follow the steps from the balanced equation to the mass of the unknown. Note that there is no shortcut from the mass of the given substance to the mass of the unknown substance. The route goes through the mole. However, you can follow the arrow from step 1 to step 3 if the amount of the given substance is in moles.

Steps in Stoichiometric Calculations

1. *Write a balanced chemical equation.* Interpret the equation in terms of moles.
2. *Determine the moles of the given substance using a mass-to-mole conversion.* Use the inverse of the molar mass as the conversion factor.
3. *Determine the moles of the unknown substance from the moles of the given substance.* Use the appropriate mole ratio from the balanced chemical equation as the conversion factor.
4. *From the moles of the unknown substance, determine the mass of the unknown substance using a mole-to-mass conversion.* Use the molar mass as the conversion factor.

Section 12.2 Assessment

15. Why is a balanced chemical equation needed in solving stoichiometric calculations?