Math Tutor — Using Mole Ratios

An unbalanced chemical equation tells you what substances react and what products are produced. A balanced chemical equation gives you even more information. It tells you how many atoms, molecules, or ions react and how many atoms, molecules, or ions are produced. The coefficients in a balanced equation represent the relative amounts in moles of reactants and products. Using this information, you can set up a mole ratio. A mole ratio is a conversion factor that relates the amounts in moles of any two substances involved in a chemical reaction.

Problem-Solving TIPS

- When solving stoichiometric problems, always start with a balanced chemical equation.
- Identify the amount known from the problem (in moles or mass).
- If you are given the mass of a substance, use the molar mass factor as a conversion factor to find the amount in moles. If you are given the amount in moles of a substance, use the molar mass factor as a conversion factor to find the mass.

Sample Problem

If 3.61 g of aluminum reacts completely with excess $CuCl_2$, what mass of copper metal is produced? Use the balanced equation below.

$$2Al(s) + 3CuCl_2(aq) \longrightarrow 2AlCl_3(aq) + 3Cu(s)$$

You know the mass of aluminum that reacts. If you convert that mass to moles, you can apply the mole ratio of aluminum to copper in this reaction to find the moles of copper produced.

$$\text{mol Al} = 3.61 \cancel{\text{g Al}} \times \frac{1 \text{ mol Al}}{26.98 \cancel{\text{g Al}}} = 0.134 \text{ mol Al}$$

$$\cancel{\text{mol Al}} \times \frac{3 \text{ mol Cu}}{2 \cancel{\text{mol Al}}} = \text{mol Cu}$$

$$0.134 \cancel{\text{mol Al}} \times \frac{3 \text{ mol Cu}}{2 \cancel{\text{mol Al}}} = 0.201 \text{ mol Cu}$$

Then, convert moles of Cu to mass of Cu by applying the following factor:

$$\text{mol Cu} \times \frac{\text{molar mass Cu}}{1 \text{ mol Cu}} = \text{mass Cu, or } 0.201 \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 12.8 \text{ g Cu}$$

Practice

1. If 12.24 moles of O_2 reacts with excess SO_2, how many moles of SO_3 are formed? Use the balanced equation below.

$$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$$

2. If 78.50 g $KClO_3$ decomposes, what mass of O_2 is produced? Use the balanced equation below.

$$2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$$

CHAPTER 9 Summary

BIG IDEA Reaction stoichiometry uses molar relationships to determine the amounts of unknown reactants or products from the amounts of known reactants or products.

SECTION 1 Introduction to Stoichiometry

KEY TERMS

composition stoichiometry
reaction stoichiometry
mole ratio

- Reaction stoichiometry involves the mass relationships between reactants and products in a chemical reaction.
- Relating one substance to another requires expressing the amount of each substance in moles.
- A mole ratio is the conversion factor that relates the amount in moles of any two substances in a chemical reaction. The mole ratio is derived from the balanced equation.
- Amount of a substance is expressed in moles, and mass of a substance is expressed by using mass units such as grams, kilograms, or milligrams.
- Mass and amount of substance are quantities, whereas moles and grams are units.
- A balanced chemical equation is necessary to solve any stoichiometric problem.

SECTION 2 Ideal Stoichiometric Calculations

- In an ideal stoichiometric calculation, the mass or the amount of any reactant or product can be calculated if the balanced chemical equation and the mass or amount of any other reactant or product are known.

SECTION 3 Limiting Reactants and Percentage Yield

KEY TERMS

limiting reactant
excess reactant
theoretical yield
actual yield
percentage yield

- In actual reactions, the reactants may be present in proportions that differ from the stoichiometric proportions required for a complete reaction in which all of each reactant is converted to product.
- The limiting reactant controls the maximum possible amount of product formed.
- For many reactions, the quantity of a product is less than the theoretical maximum for that product. Percentage yield shows the relationship between the theoretical yield and actual yield for the product of a reaction.

CHAPTER 9 Review

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SECTION 1

Introduction to Stoichiometry

REVIEWING MAIN IDEAS

1. **a.** Explain the concept of mole ratio as used in reaction stoichiometry problems.
   b. What is the source of this ratio?

2. For each of the following balanced chemical equations, write all possible mole ratios:
   a. $2Ca + O_2 \longrightarrow 2CaO$
   b. $Mg + 2HF \longrightarrow MgF_2 + H_2$

PRACTICE PROBLEMS

3. Given the chemical equation $Na_2CO_3(aq) + Ca(OH)_2 \longrightarrow 2NaOH(aq) + CaCO_3(s)$, determine to two decimal places the molar masses of all substances. Write molar masses as conversion factors.

SECTION 2

Ideal Stoichiometric Calculations

REVIEWING MAIN IDEAS

4. **a.** What is molar mass?
   b. What is its role in reaction stoichiometry?

PRACTICE PROBLEMS

5. Hydrogen and oxygen react under a specific set of conditions to produce water according to the following: $2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$.
   a. How many moles of hydrogen would be required to produce 5.0 mol of water?
   b. How many moles of oxygen would be required? (Hint: See Sample Problem A.)

6. **a.** If 4.50 mol of ethane, C_2H_6, undergoes combustion according to the unbalanced equation $C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$, how many moles of oxygen are required?
   b. How many moles of each product are formed?

7. Sodium chloride is produced from its elements through a synthesis reaction. What mass of each reactant would be required to produce 25.0 mol of sodium chloride?

8. In a blast furnace, iron(lll) oxide is used to produce iron by the following (unbalanced) reaction:
   $Fe_2O_3(s) + CO(g) \longrightarrow Fe(s) + CO_2(g)$
   a. If 4.00 kg Fe_2O_3 is available to react, how many moles of CO are needed?
   b. How many moles of each product are formed?

9. Methanol, CH_3OH, is an important industrial compound that is produced from the following (unbalanced) reaction: $CO(g) + H_2(g) \longrightarrow CH_3OH(g)$. What mass of each reactant would be needed to produce 100.0 kg of methanol? (Hint: See Sample Problem E.)

10. During lightning flashes, nitrogen combines with oxygen in the atmosphere to form nitrogen monoxide, NO, which then reacts further with O_2 to produce nitrogen dioxide, NO_2.
    a. What mass of NO_2 is formed when NO reacts with 384 g O_2?
    b. How many grams of NO are required to react with this amount of O_2?

11. As early as 1938, the use of NaOH was suggested as a means of removing CO_2 from the cabin of a spacecraft according to the following (unbalanced) reaction: $NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$.
    a. If the average human body discharges 925.0 g CO_2 per day, how many moles of NaOH are needed each day for each person in the spacecraft?
    b. How many moles of each product are formed?

12. The double-replacement reaction between silver nitrate and sodium bromide produces silver bromide, a component of photographic film.
    a. If 4.50 mol of silver nitrate reacts, what mass of sodium bromide is required?
    b. What mass of silver bromide is formed?

13. In a soda-acid fire extinguisher, concentrated sulfuric acid reacts with sodium hydrogen carbonate to produce carbon dioxide, sodium sulfate, and water.
    a. How many moles of sodium hydrogen carbonate would be needed to react with 150.0 g of sulfuric acid?
    b. How many moles of each product would be formed?

14. Sulfuric acid reacts with sodium hydroxide according to the following:

$$H_2SO_4 + NaOH \longrightarrow Na_2SO_4 + H_2O$$

- **a.** Balance the equation for this reaction.
- **b.** What mass of H_2SO_4 would be required to react with 0.75 mol NaOH?
- **c.** What mass of each product is formed by this reaction? (Hint: See Sample Problem B.)

15. Copper reacts with silver nitrate through single replacement.

- **a.** If 2.25 g of silver is produced from the reaction, how many moles of copper(II) nitrate are also produced?
- **b.** How many moles of each reactant are required in this reaction? (Hint: See Sample Problem D.)

16. Aspirin, $C_9H_8O_4$, is produced through the following reaction of salicylic acid, $C_7H_6O_3$, and acetic anhydride, $C_4H_6O_3$: $C_7H_6O_3(s) + C_4H_6O_3(l) \longrightarrow C_9H_8O_4(s) + HC_2H_3O_2(l)$.

- **a.** What mass of aspirin (kg) could be produced from 75.0 mol of salicylic acid?
- **b.** What mass of acetic anhydride (kg) would be required?
- **c.** At 20°C, how many liters of acetic acid, $HC_2H_3O_2$, would be formed? The density of $HC_2H_3O_2$ is 1.05 g/mL.

SECTION 3

Limiting Reactants and Percentage Yield

REVIEWING MAIN IDEAS

17. Distinguish between ideal and real stoichiometric calculations.

18. Distinguish between the limiting reactant and the excess reactant in a chemical reaction.

19.

- **a.** Distinguish between the theoretical yield and actual yield in stoichiometric calculations.
- **b.** How does the value of the theoretical yield generally compare with the value of the actual yield?

20. What is the percentage yield of a reaction?

21. Why are actual yields usually less than calculated theoretical yields?

PRACTICE PROBLEMS

22. Given the reactant amounts specified in each chemical equation, determine the limiting reactant in each case:

- **a.** $\underset{2.0\ mol}{HCl} + \underset{2.5\ mol}{NaOH} \longrightarrow NaCl + H_2O$
- **b.** $\underset{2.5\ mol}{Zn} + \underset{6.0\ mol}{2HCl} \longrightarrow ZnCl_2 + H_2$
- **c.** $\underset{4.0\ mol}{2Fe(OH)_3} + \underset{6.5\ mol}{3H_2SO_4} \longrightarrow Fe_2(SO_4)_3 + 6H_2O$

(Hint: See Sample Problem F.)

23. For each reaction specified in Problem 22, determine the amount in moles of excess reactant that remains. (Hint: See Sample Problem G.)

24. For each reaction specified in Problem 22, calculate the amount in moles of each product formed.

25.

- **a.** If 2.50 mol of copper and 5.50 mol of silver nitrate are available to react by single replacement, identify the limiting reactant.
- **b.** Determine the amount in moles of excess reactant remaining.
- **c.** Determine the amount in moles of each product formed.
- **d.** Determine the mass of each product formed.

26. Sulfuric acid reacts with aluminum hydroxide by double replacement.

- **a.** If 30.0 g of sulfuric acid reacts with 25.0 g of aluminum hydroxide, identify the limiting reactant.
- **b.** Determine the mass of excess reactant remaining.
- **c.** Determine the mass of each product formed. Assume 100% yield.

27. The energy used to power one of the Apollo lunar missions was supplied by the following overall reaction: $2N_2H_4 + (CH_3)_2N_2H_2 + 3N_2O_4 \longrightarrow 6N_2 + 2CO_2 + 8H_2O$. For the phase of the mission when the lunar module ascended from the surface of the moon, a total of 1200. kg N_2H_4 was available to react with 1000. kg $(CH_3)_2N_2H_2$ and 4500. kg N_2O_4.

- **a.** For this portion of the flight, which of the allocated components was used up first?
- **b.** How much water, in kilograms, was put into the lunar atmosphere through this reaction?

28. Calculate the indicated quantity for each of the various chemical reactions given:
- **a.** theoretical yield = 20.0 g, actual yield = 15.0 g, percentage yield = ?
- **b.** theoretical yield = 1.0 g, percentage yield = 90.0%, actual yield = ?
- **c.** theoretical yield = 5.00 g, actual yield = 4.75 g, percentage yield = ?
- **d.** theoretical yield = 3.45 g, percentage yield = 48.0%, actual yield = ?

29. The percentage yield for the reaction

$$PCl_3 + Cl_2 \longrightarrow PCl_5$$

is 83.2%. What mass of PCl_5 is expected from the reaction of 73.7 g PCl_3 with excess chlorine?

30. The Ostwald process for producing nitric acid from ammonia consists of the following steps:

$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$

$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$

$3NO_2(g) + H_2O(g) \longrightarrow 2HNO_3(aq) + NO(g)$

If the yield in each step is 94.0%, how many grams of nitric acid can be produced from 5.00 kg of ammonia?

Mixed Review

REVIEWING MAIN IDEAS

31. Magnesium is obtained from sea water. $Ca(OH)_2$ is added to sea water to precipitate $Mg(OH)_2$. The precipitate is filtered and reacted with HCl to produce $MgCl_2$. The $MgCl_2$ is electrolyzed to produce Mg and Cl_2. If 185.0 g of magnesium is recovered from 1000. g $MgCl_2$, what is the percentage yield for this reaction?

32. Phosphate baking powder is a mixture of starch, sodium hydrogen carbonate, and calcium dihydrogen phosphate. When mixed with water, phosphate baking powder releases carbon dioxide gas, causing a dough or batter to bubble and rise.

$2NaHCO_3(aq) + Ca(H_2PO_4)_2(aq) \longrightarrow Na_2HPO_4(aq) + CaHPO_4(aq) + 2CO_2(g) + 2H_2O(l)$

If 0.750 L CO_2 is needed for a cake and each kilogram of baking powder contains 168 g of $NaHCO_3$, how many grams of baking powder must be used to generate this amount of CO_2? The density of CO_2 at baking temperature is about 1.20 g/L.

33. Coal gasification is a process that converts coal into methane gas. If this reaction has a percentage yield of 85.0%, what mass of methane can be obtained from 1250 g of carbon?

$$2C(s) + 2H_2O(l) \longrightarrow CH_4(g) + CO_2(g)$$

34. If the percentage yield for the coal gasification process is increased to 95%, what mass of methane can be obtained from 2750 g of carbon?

35. Builders and dentists must store plaster of Paris, $CaSO_4 \bullet \frac{1}{2}H_2O$, in airtight containers to prevent it from absorbing water vapor from the air and changing to gypsum, $CaSO_4 \bullet 2H_2O$. How many liters of water vapor evolve when 2.00 kg of gypsum is heated at 110°C to produce plaster of Paris? At 110°C, the density of water vapor is 0.574 g/L.

36. Gold can be recovered from sea water by reacting the water with zinc, which is refined from zinc oxide. The zinc displaces the gold in the water. What mass of gold can be recovered if 2.00 g of ZnO and an excess of sea water are available?

$2ZnO(s) + C(s) \longrightarrow 2Zn(s) + CO_2(g)$

$2Au^{3+}(aq) + 3Zn(s) \longrightarrow 3Zn^{2+}(aq) + 2Au(s)$

CRITICAL THINKING

37. Relating Ideas The chemical equation is a good source of information concerning a reaction. Explain the relationship between the actual yield of a reaction product and the chemical equation of the product.

38. Analyzing Results Very seldom are chemists able to achieve a 100% yield of a product from a chemical reaction. However, the yield of a reaction is usually important because of the expense involved in producing less product. For example, when magnesium metal is heated in a crucible at high temperatures, the product magnesium oxide, MgO, is formed. Based on your analysis of the reaction, describe some of the actions that you would take to increase your percentage yield. The reaction is as follows:

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

39. Analyzing Results In the lab, you run an experiment that appears to have a percentage yield of 115%. Propose reasons for this result. Can an actual yield ever exceed a theoretical yield? Explain your answer.

40. Relating Ideas Explain the stoichiometry of blowing air on a smoldering campfire to keep the coals burning.

USING THE HANDBOOK

41. The steel-making process described in the Transition Metal section of the *Elements Handbook* (Appendix A) shows the equation for the formation of iron carbide. Use this equation to answer the following questions:

a. If 3.65×10^3 kg of iron is used in a steel-making process, what is the minimum mass of carbon needed to react with all of the iron?

b. What is the theoretical mass of iron carbide that is formed?

42. The reaction of aluminum with oxygen to produce a protective coating for the metal's surface is described in the discussion of aluminum in Group 13 of the *Elements Handbook* (Appendix A). Use this equation to answer the following questions:

a. What mass of aluminum oxide would theoretically be formed if a 30.0 g piece of aluminum foil reacted with excess oxygen?

b. Why would you expect the actual yield from this reaction to be far less than the mass you calculated in item (a)?

43. The reactions of oxide compounds to produce carbonates, phosphates, and sulfates are described in the section on oxides in Group 16 of the *Elements Handbook* (Appendix A). Use those equations to answer the following questions:

a. What mass of CO_2 is needed to react with 154.6 g MgO?

b. What mass of magnesium carbonate is produced?

c. When 45.7 g P_4O_{10} is reacted with an excess of calcium oxide, what mass of calcium phosphate is produced?

RESEARCH AND WRITING

44. Research the history of the Haber process for the production of ammonia. What was the significance of this process in history? How is this process related to the discussion of reaction yields in this chapter?

ALTERNATIVE ASSESSMENT

45. Performance Just as reactants combine in certain proportions to form a product, colors can be combined to create other colors. Artists do this all the time to find just the right color for their paintings. Using poster paint, determine the proportions of primary pigments used to create the following colors. Your proportions should be such that anyone could mix the color perfectly.

46. Performance Write two of your own sample problems that are descriptions of how to solve a mass-mass problem. Assume that your sample problems will be used by other students to learn how to solve mass-mass problems.