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Unit IV - Lecture 12

Chemistry

The Molecular Nature of Matter and Change

Fifth Edition

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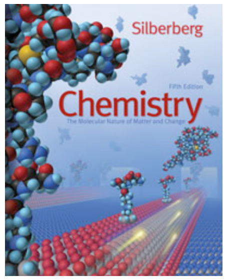


Chapter 3

Stoichiometry of Formulas and Equations

Mole - Mass Relationships in Chemical Systems

3.3 Writing and Balancing Chemical Equations

3.4 Calculating the Amounts of Reactant and Product

3.5 Fundamentals of Solution Stoichiometry

Figure 3.7

The formation of HF gas on the macroscopic and molecular levels.

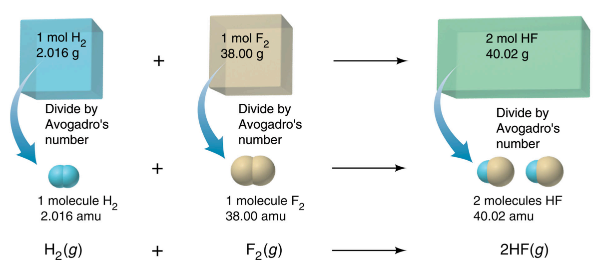
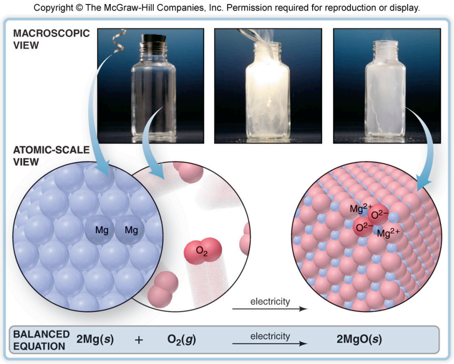


Figure 3.8 **A three-level view of the chemical reaction in a flashbulb.**



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Balancing Chemical Equations

translate the statement

balance the atoms

adjust the coefficients

check the atom balance

specify states of matter

Sample Problem 3.8 Balancing Chemical Equations

PROBLEM: Within the cylinders of a car's engine, the hydrocarbon octane (C_8H_{18}), one of many components of gasoline, mixes with oxygen from the air and burns to form carbon dioxide and water vapor. Write a balanced equation for this reaction.

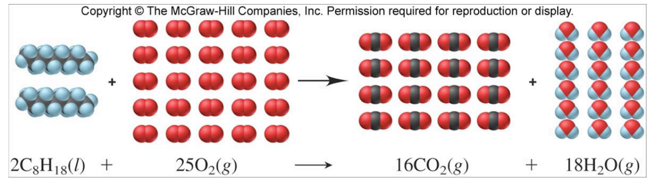
PLAN: **SOLUTION:**

translate the statement	$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$
balance the atoms	$C_8H_{18} + 25/2\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$
adjust the coefficients	$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$
check the atom balance	$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$
specify states of matter	$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$

Molecular Scene

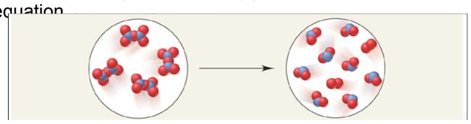
Molecular Scene

Combustion of Octane



Sample Problem 3.9 Balancing an Equation from a Molecular Depiction

PROBLEM: This molecular scene depicts an important reaction in nitrogen chemistry (nitrogen is blue, oxygen is red). Write a balanced equation.



PLAN: Determine the number and formulas of each molecule. Arrange this information in equation format using the smallest whole-number coefficients. Add the appropriate states of matter.

SOLUTION: Reactant circle has one type of molecule with two N and five O, N_2O_5.

Four molecules present. Product circle has two different molecules.

First molecule has one N and two O, NO_2, and the other two O, O_2.

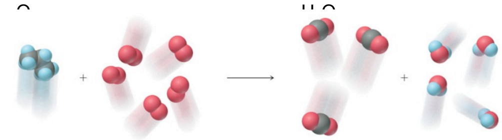
$4N_2O_5 \rightarrow 8NO_2 + 2O_2$

$2N_2O_5 \rightarrow 4NO_2 + O_2$

There are eight NO_2 and two O_2 molecules.

Table 3.5 Information Contained in a Balanced Equation

Viewed in Terms of	Reactants $C_3H_8(g) + 5O_2(g)$		Products $3CO_2(g) + 4H_2O(g)$
Molecules	1 molecule C_3H_8 + 5 molecules O_2	$\rightarrow$	3 molecules CO_2 + 4 molecules H_2O



Amount (mol)	1 mol C_3H_8 + 5 mol O_2	$\rightarrow$	3 mol CO_2 + 4 mol H_2O
Mass (amu)	44.09 amu C_3H_8 + 160.00 amu O_2	$\rightarrow$	132.03 amu CO_2 + 72.06 amu H_2O
Mass (g)	44.09 g C_3H_8 + 160.00 g O_2	$\rightarrow$	132.03 g CO_2 + 72.06 g H_2O
Total Mass (g)	204.09 g	$\rightarrow$	204.09 g

Solving Stoichiometry Problems

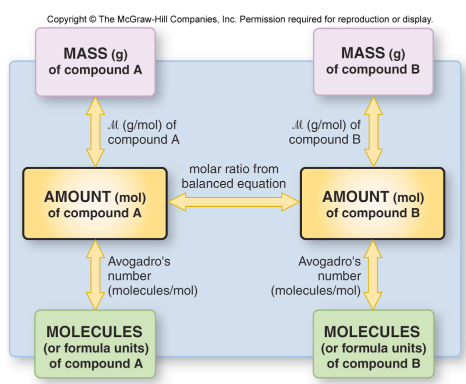
write balanced equation

convert mass to moles

use mole ratios

convert moles to mass

Figure 3.9 Summary of the mass-mole-number relationships in a chemical reaction.



Sample Problem 3.10 **Calculating Amounts of Reactants and Products**

PROBLEM: Copper is obtained from copper(I) sulfide by roasting it in the presence of oxygen gas) to form powdered copper(I) oxide and gaseous sulfur dioxide.

(a) How many moles of oxygen are required to roast 10.0 mol of copper(I) sulfide?

(b) How many grams of sulfur dioxide are formed when 10.0 mol of copper(I) sulfide is roasted?

(c) How many kilograms of oxygen are required to form 2.86 kg of copper(I) oxide?

PLAN: write and balance equation

find mols O_2 | find mols SO_2 | find mols Cu_2O

find g SO_2 | find mols O_2

find kg O_2

Sample Problem 3.10 **Calculating Amounts of Reactants and Products**

SOLUTION: $2Cu_2S(s) + 3O_2(g) \rightarrow 2Cu_2O(s) + 2SO_2(g)$

(a) *How many moles of oxygen are required to roast 10.0 mol of copper(I) sulfide?*

$$10.0\ \cancel{mol}\ Cu_2S \quad \frac{3\ mol\ O_2}{2\ \cancel{mol}\ Cu_2S} = 15.0\ mol\ O_2$$

(b) *How many grams of sulfur dioxide are formed when 10.0 mol of copper(I) sulfide is roasted?*

$$10.0\ \cancel{mol}\ Cu_2S \quad \frac{2\ \cancel{mol}\ SO_2}{2\ \cancel{mol}\ Cu_2S} \quad \frac{64.07\ g\ SO_2}{\cancel{mol}\ SO_2} = 641\ g\ SO_2$$

(c) *How many kilograms of oxygen are required to form 2.86 kg of copper(I) oxide?*

$$2.86\ \cancel{kg}\ Cu_2O \quad \frac{10^3\ g\ Cu_2O}{\cancel{kg}\ Cu_2O} \quad \frac{mol\ Cu_2O}{143.10\ \cancel{g}\ Cu_2O} = 20.0\ mol\ Cu_2O$$

$$20.0\ \cancel{mol}\ Cu_2O \quad \frac{3\ \cancel{mol}\ O_2}{2\ \cancel{mol}\ Cu_2O} \quad \frac{32.00\ \cancel{g}\ O_2}{\cancel{mol}\ O_2} \quad \frac{kg\ O_2}{10^3\ \cancel{g}\ O_2} = 0.959\ kg\ O_2$$

Sample Problem 3.11 **Writing an Overall Equation for a Reaction Sequence**

PROBLEM: Roasting is the first step in extracting copper from chalcocite, the ore used in the previous problem. In the next step, copper(I) oxide reacts with powdered carbon to yield copper metal and carbon monoxide gas. Write a balanced overall equation for the two-step process.

PLAN: Write balanced equations for each step. Adjust coefficients so common product in step 1 is used up in step 2. Add equations and cancel common substances.

SOLUTION: $\boxed{2Cu_2S(s) + 3O_2(g) \rightarrow 2Cu_2O(s) + 2SO_2(g)}$

$Cu_2O(s) + C(s) \rightarrow Cu(s) + CO(g)$ multiply all coefficients by 2

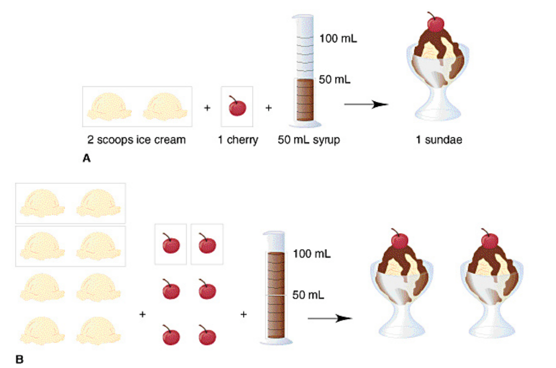
therefore: $\boxed{2Cu_2O(s) + 2C(s) \rightarrow 4Cu(s) + 2CO(g)}$

add boxed equations:

$2Cu_2S(s) + 3O_2(g) + \cancel{2Cu_2O(s)} + 2C(s) \rightarrow \cancel{2Cu_2O(s)} + 4Cu(s) + 2SO_2(g) + 2CO(g)$

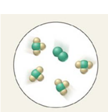
or $2Cu_2S(s) + 3O_2(g) + 2C(s) \rightarrow 4Cu(s) + 2SO_2(g) + 2CO(g)$

Figure 3.10 **An ice cream sundae analogy for limiting reactions.**



Sample Problem 3.12 **Using Molecular Depictions to Solve a Limiting-Reactant Problem**

PROBLEM: Chlorine trifluoride, an extremely reactive substance, is formed as a gas by the reaction of elemental chlorine (green spheres) and fluorine.

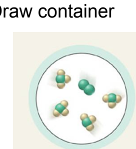


(a) Name the limiting reactant, and draw the container contents after the reaction is complete.

(b) When the reaction is run again with 0.750 mol of Cl_2 and 3 mol of F_2, what mass of chlorine trifluoride will be prepare

PLAN: Write a balanced chemical equation. Determine the number of reactants available, number of products that can be formed, reactant used up first is the limiting reactant. Draw container contents after reaction.

SOLUTION: $Cl_2(g) + 3F_2(g) \rightarrow 2ClF_3(g)$



(a) 1 Cl_2 molecules to 3 F_2 molecules form 2 ClF_3 molecules. There are 3 Cl_2 and 6 F_2. 3 Cl_2 requires 9 F_2 and 6 F_2 requires 2 Cl_2. Therefore, F_2 is limiting and 1 Cl_2 will remain after the reaction that

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Sample Problem 3.12 **Using Molecular Depictions to Solve a Limiting-Reactant Problem**

$Cl_2(g) + 3F_2(g) \rightarrow 2ClF_3(g)$

(b) When the reaction is run again with 0.750 mol of Cl2 and 3.00 mol of F2, what mass of chlorine trifluoride will be prepared?

PLAN: **(b)** Determine limiting reactant and calculate grams of ClF_3.

SOLUTION:

(b) Moles ClF_3 = $0.750\ \cancel{mol}\ Cl_2 \times \frac{2\ mol\ ClF_3}{1\ \cancel{mol}\ Cl_2} = 1.50\ mol\ ClF_3$

Moles ClF_3 = $3.00\ \cancel{mol}\ F_2 \times \frac{2\ mol\ ClF_3}{3\ \cancel{mol}\ F_2} = 2.00\ mol\ ClF_3$

Mass (g) ClF_3 = $1.50\ \cancel{mol}\ ClF_3 \times \frac{92.45\ g\ ClF_3}{1\ \cancel{mol}\ ClF_3} = 138.7\ g\ ClF_3$

Sample Problem 3.13 **Calculating Amounts of Reactant and Product in Reactions Involving a Limiting Reactant**

PROBLEM: Hydrazine(N_2H_4) and dinitrogen tetraoxide(N_2O_4) ignite on contact to form nitrogen gas and water vapor. How many grams of nitrogen gas form when 1.00×10^2 g of N_2H_4 and 2.00×10^2 g of N_2O_4 are mixed?

PLAN: Write a balanced chemical equation. Find the number of moles of reactants given. Determine limiting reactant, number of moles and grams of product formed.

mass of N_2H_4 mass of N_2O_4

divide by $\mathcal{M}$

mol of N_2H_4 mol of N_2O_4

molar ratio

mol of N_2 mol of N_2

limiting mol N_2

multiply by $\mathcal{M}$

g N_2

Sample Problem 3.13 **Calculating Amounts of Reactant and Product in Reactions Involving a Limiting Reactant**

SOLUTION: $2\ N_2H_4(l) + N_2O_4(l) \longrightarrow 3\ N_2(g) + 4\ H_2O(g)$

Moles of N_2 from moles N_2H_4

$1.00 \times 10^2\ \cancel{g}\ N_2H_4 \times \frac{\text{mol } N_2H_4}{32.05\ \cancel{g}\ N_2H_4} = 3.12$ mol N_2H_4

$3.12\ \cancel{mol}\ N_2H_4 \times \frac{3\ \text{mol } N_2}{2\ \cancel{mol}\ N_2H_4} = 4.68$ mol N_2

Moles of N_2 from moles N_2O_4

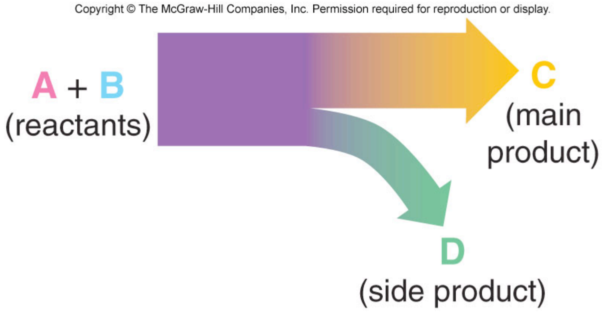
$2.00 \times 10^2\ \cancel{g}\ N_2O_4 \times \frac{\text{mol } N_2O_4}{92.02\ \cancel{g}\ N_2O_4} = 2.17$ mol N_2O_4

$2.17\ \cancel{mol}\ N_2O_4 \times \frac{3\ \text{mol } N_2}{\cancel{mol}\ N_2O_4} = 6.51$ mol N_2

N_2H_4 is the limiting reactant because it produces less product, N_2, than does N_2O_4.

$4.68\ \cancel{mol}\ N_2 \times \frac{28.02\ \text{g}}{\cancel{mol}\ N_2} = 131$ g N_2

Figure 3.11 **The effect of side reactions on yield.**



Sample Problem 3.14 **Calculating Percent Yield**

PROBLEM: Silicon carbide (SiC) is made by reacting sand(silicon dioxide, SiO2) with powdered carbon at high temperature. Carbon monoxide is also formed. What is the percent yield if 51.4 kg of SiC is recovered from processing 100.0 kg of sand?

PLAN:

write balanced equation

find mol reactant

find mol product

find g product predicted

percent yield

actual yield/theoretical yield x 100

SOLUTION: $SiO_2(s) + 3C(s) \longrightarrow SiC(s) + 2CO(g)$

$100.0\ \cancel{kg}\ SiO_2 \times \frac{10^3\ \cancel{g}}{\cancel{kg}} \times \frac{\text{mol } SiO_2}{60.09\ \cancel{g}\ SiO_2} = 1664$ mol SiO_2

mol SiO_2 = mol SiC = 1664

$1664\ \cancel{mol}\ SiC \times \frac{40.10\ \cancel{g}}{\cancel{mol}\ SiC} \times \frac{kg}{10^3\ \cancel{g}} = 66.73$ kg

$\frac{51.4\ \text{kg}}{66.73\ \text{kg}} \times 100 = 77.0\%$

Sample Problem 3.15 **Calculating the Molarity of a Solution**

PROBLEM: What is the molarity of an aqueous solution that contains 0.715 mol of glycine (H_2NCH_2COOH) in 495 mL?

PLAN: Molarity is the number of moles of solute per liter of solution.

mol of glycine

divide by volume

concentration (mol/mL) glycine

10^3 mL = 1 L

molarity (mol/L) glycine

SOLUTION:

$\frac{0.715\ \text{mol glycine}}{495\ \cancel{mL}\ \text{soln}} \times \frac{1000\ \cancel{mL}}{1\ \text{L}} = 1.44$ M glycine

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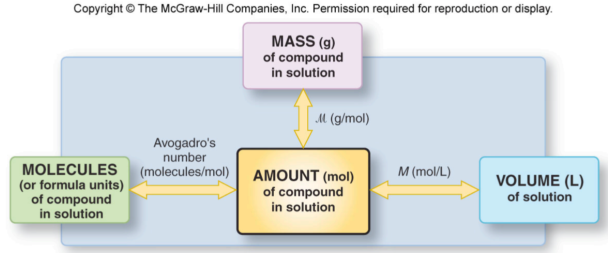
Figure 3.12 **Summary of mass-mole-number-volume relationships in solution.**



Sample Problem 3.16 **Calculating Mass of Solute in a Given Volume of Solution**

PROBLEM: How many grams of solute are in 1.75 L of 0.460 M sodium monohydrogen phosphate buffer solution?

PLAN: Calculate the # moles of solute using given the molarity and volume. The formula for the solute is Na_2HPO_4. Determine mass of solute.

volume of soln

multiply by M

moles of solute

multiply by $\mathcal{M}$

grams of solute

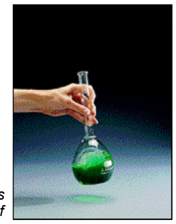
SOLUTION:

$$1.75\ \cancel{L} \times \frac{0.460\ \text{moles}}{1\ \cancel{L}} = 0.805\ \text{mol}\ Na_2HPO_4$$

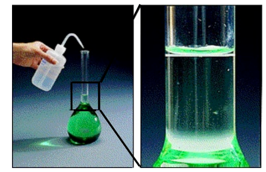
$$0.805\ \cancel{\text{mol}}\ Na_2HPO_4 \times \frac{141.96\ \text{g}\ Na_2HPO_4}{\cancel{\text{mol}}\ Na_2HPO_4} = 114\ \text{g}\ Na_2HPO_4$$

Figure 3.13 **Laboratory preparation of molar solutions.**

A
•Weigh the solid needed.
•Transfer the solid to a volumetric flask that contains about half the final volume of solvent.

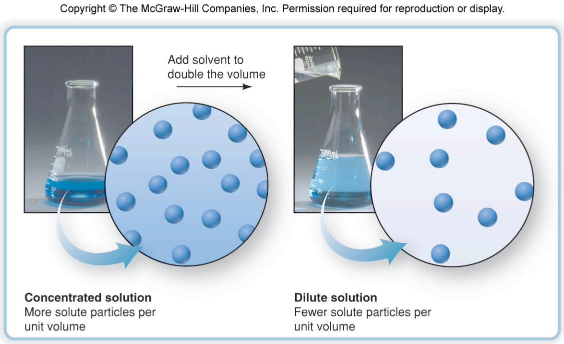


B *Dissolve the solid thoroughly by swirling.*



C *Add solvent until the solution reaches its final volume.*

Figure 3.14
Converting a concentrated solution to a dilute solution.



Sample Problem 3.17 **Preparing a Dilute Solution from a Concentrated Solution**

PROBLEM: "Isotonic saline" is a 0.15 M aqueous solution of NaCl.. How would you prepare 0.80 L of isotonic saline from a 6.0 M stock solution?

PLAN: Number of moles of solute does not change during dilution but the volume does. The new volume will be the sum of the two volumes, that is, the total final volume.

volume of dilute soln

multiply by M of dilute solution

moles of NaCl in dilute soln = mol NaCl in concentrated soln

divide by M of concentrated soln

L of concentrated soln

$$M_{dil} \times V_{dil} = \#\ \text{mol solute} = M_{conc} \times V_{conc}$$

SOLUTION:

$$0.80\ \text{L}\ \cancel{\text{soln}} \times \frac{0.15\ \text{mol NaCl}}{\text{L}\ \cancel{\text{soln}}} = 0.12\ \text{mol NaCl}$$

$$0.12\ \cancel{\text{mol}}\ \text{NaCl} \times \frac{\text{L soln}}{6\ \cancel{\text{mol}}} = 0.020\ \text{L soln}$$

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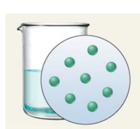
Sample Problem 3.18 **Visualizing Changes in Concentration**

PROBLEM: The beaker and circle represents a unit volume of solution. Draw the solution after each of these changes:

(a) For every 1 mL of solution, 1 mL of solvent is added.

(b) One third of the solutions volume is boiled off.



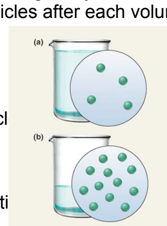
PLAN: The total number of solute particles does not change only the volume of the solution. Find the number of solute particles after each volume change.

SOLUTION:

$$N_{dil} \times V_{dil} = N_{conc} \times V_{conc}$$

(a) $N_{dil} = N_{conc} \times \frac{V_{conc}}{V_{dil}} = 8\ \text{particles} \times \frac{1\ \cancel{\text{mL}}}{2\ \cancel{\text{mL}}} = 4\ \text{particl}$

(b) $N_{conc} = N_{dil} \times \frac{V_{dil}}{V_{conc}} = 8\ \text{particles} \times \frac{1\ \cancel{\text{mL}}}{2/3\ \cancel{\text{mL}}} = 12\ \text{parti}$



Sample Problem 3.19 **Calculating Amounts of Reactants and Products for a Reaction in Solution**

PROBLEM: A 0.10M HCl solution is used to simulate the acid concentration of the stomach. How many liters of "stomach acid" react with a tablet containing 0.10g of magnesium hydroxide?

PLAN: Write a balanced equation. Calculate the moles of $Mg(OH)_2$. Determine the moles acid, then the volume of acid solution needed to neutralize the antacid.

mass $Mg(OH)_2$

divide by

mol $Mg(OH)_2$

mol ratio

mol HCl

divide by

L HCl $\mathcal{M}$

SOLUTION:

$$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$$

$$0.10\ \cancel{\text{g}}\ Mg(OH)_2 \times \frac{\text{mol}\ Mg(OH)_2}{58.33\ \cancel{\text{g}}\ Mg(OH)_2} = 1.7\times10^{-3}\ \text{mol}\ Mg(OH)_2$$

$$1.7\times10^{-3}\ \cancel{\text{mol}}\ Mg(OH)_2 \times \frac{2\ \text{mol HCl}}{1\ \cancel{\text{mol}}\ Mg(OH)_2} = 3.4\times10^{-3}\ \text{mol HCl}$$

$$3.4\times10^{-3}\ \cancel{\text{mol}}\ \text{HCl} \times \frac{1\text{L}}{0.10\ \cancel{\text{mol}}\ \text{HCl}} = 3.4\times10^{-2}\ \text{L HCl}$$

Sample Problem 3.20 Solving Limiting-Reactant Problems for Reactions in Solution

PROBLEM: In a simulation mercury removal from industrial wastewater, 0.050L of 0.010M mercury(II) nitrate reacts with 0.020L of 0.10M sodium sulfide. How many grams of mercury(II) sulfide form?

PLAN: Write a balanced chemical reaction. Determine limiting reactant. Calculate the grams of mercury(II) sulfide product.

SOLUTION: $Hg(NO_3)_2(aq) + Na_2S(aq) \longrightarrow HgS(s) + 2NaNO_3(aq)$

L of $Hg(NO_3)_2$ — L of Na_2S

multiply by M — multiply by M

mol $Hg(NO_3)_2$ — mol Na_2S

mol ratio — mol ratio

mol HgS — mol HgS

$0.050\ \cancel{L}\ Hg(NO_3)_2 \times 0.010\ \cancel{mol/L} \times \frac{1\ mol\ HgS}{1\ \cancel{mol}\ Hg(NO_3)_2} = 5.0\times10^{-4}$ mol HgS

$0.020\ \cancel{L}\ Hg(NO_3)_2 \times 0.10\ \cancel{mol/L} \times \frac{1\ mol\ HgS}{1\ \cancel{mol}\ Na_2S} = 2.0\times10^{-3}$ mol HgS

$Hg(NO_3)_2$ is the limiting reagent.

$5.0\times10^{-4}\ \cancel{mol}\ HgS \times \frac{232.7\ g\ HgS}{1\ \cancel{mol}\ HgS}$ = 0.12 g HgS

Figure 3.15 **An overview of the key mass-mole-number stoichiometric relationships.**