Steven S. Zumdahl
Susan A. Zumdahl
Donald J. DeCoste

Chapter 9

Chemical Quantities

Gretchen M. Adams • University of Illinois at Urbana-Champaign

Objectives

1. To understand the information given in a balanced equation
2. To use a balanced equation to determine relationships between moles of reactant and products

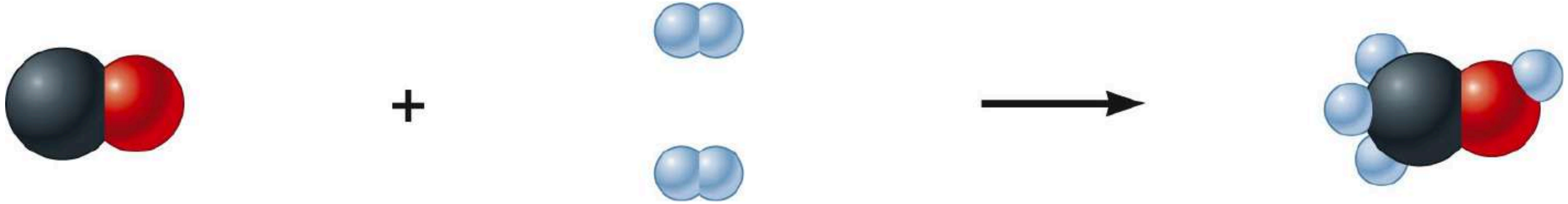
A. Information Given by Chemical Equations

- A balanced chemical equation gives relative numbers (or moles) of reactant and product molecules that participate in a chemical reaction.
- The coefficients of a balanced equation give the relative numbers of molecules.

$$CO(g) \quad + \quad 2\ H_2(g) \quad \rightarrow \quad CH_3OH(l)$$

$$1C\ \ 1O \qquad\qquad 4H \qquad\qquad 1C\ \ 1O\ \ 4H$$

Using Chemical Equations



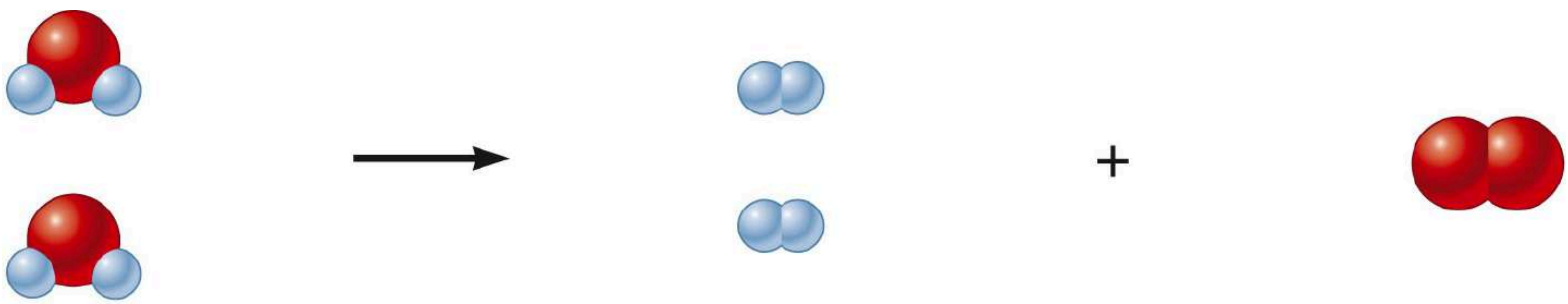
$$12[CO(g) + 2\,H_2(g) \rightarrow CH_3OH(l)]$$

⇩

$$12\,CO(g) + 24\,H_2(g) \rightarrow 12\,CH_3OH(l)$$

B. Mole-mole Relationships

- A balanced equation can predict the moles of product that a given number of moles of reactants will yield.



$2H_2O(l) \qquad 2H_2(g) + O_2(g)$

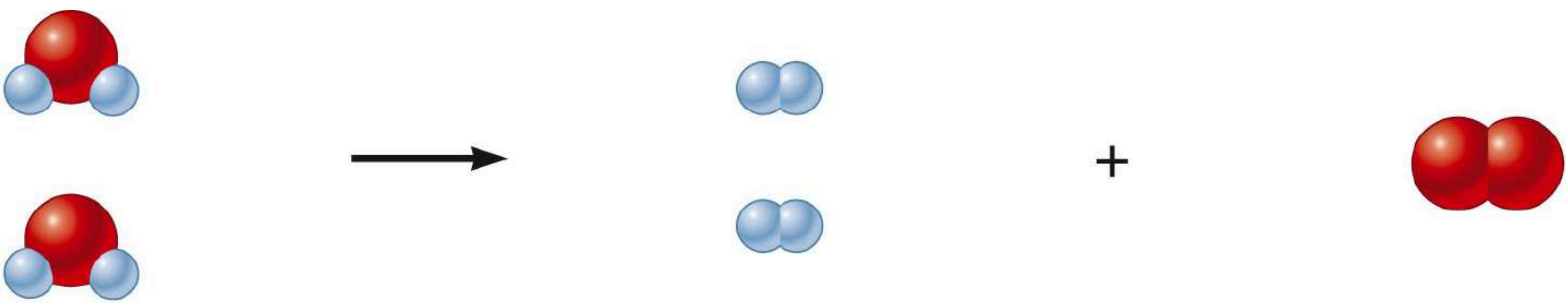
$$1 \text{ dozen } CO(g) + 2 \text{ dozen } H_2(g) \rightarrow 1 \text{ dozen } CH_3OH(l)$$

B. Mole-mole Relationships

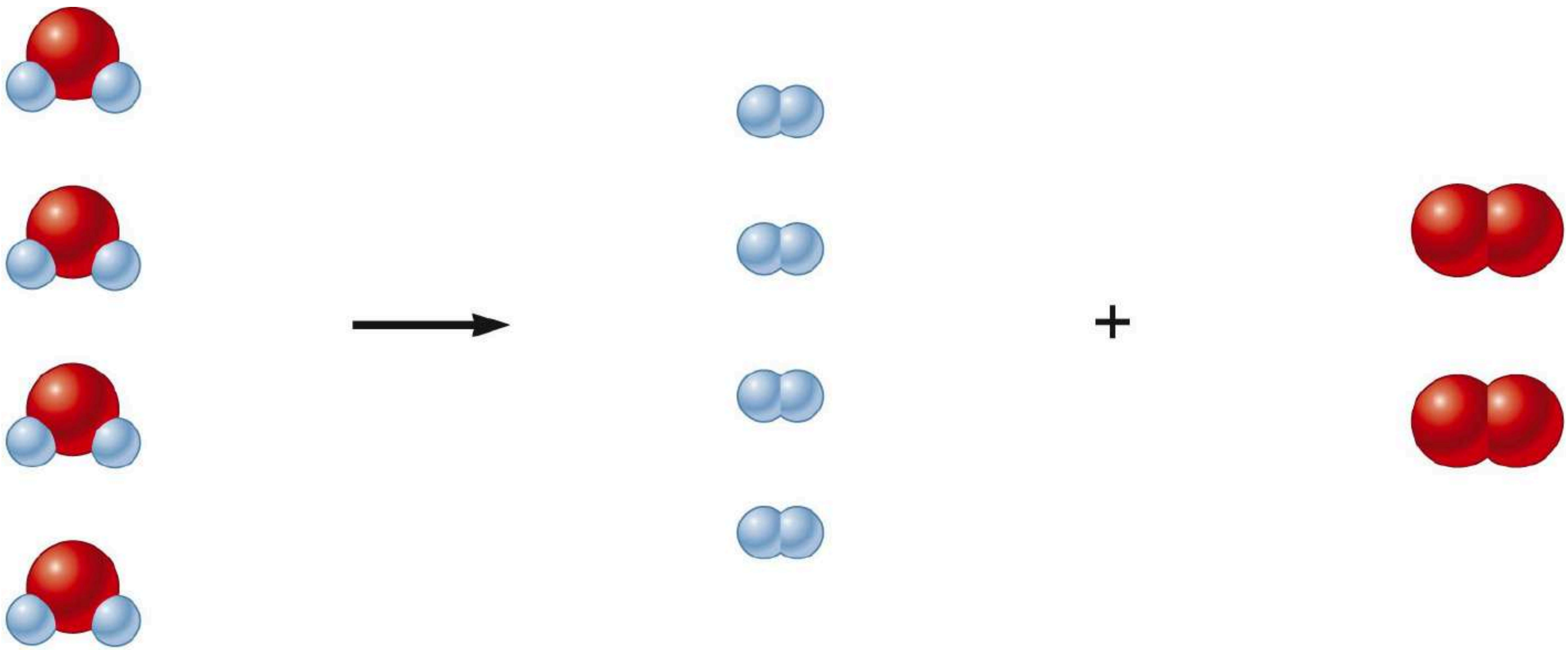
- The mole ratio allows us to convert from moles of one substance in a balanced equation to moles of a second substance in the equation.

B. Mole-mole Relationships

- A balanced equation can predict the moles of product that a given number of moles of reactants will yield.



$2H_2O(l) \qquad 2H_2(g) + O_2(g)$

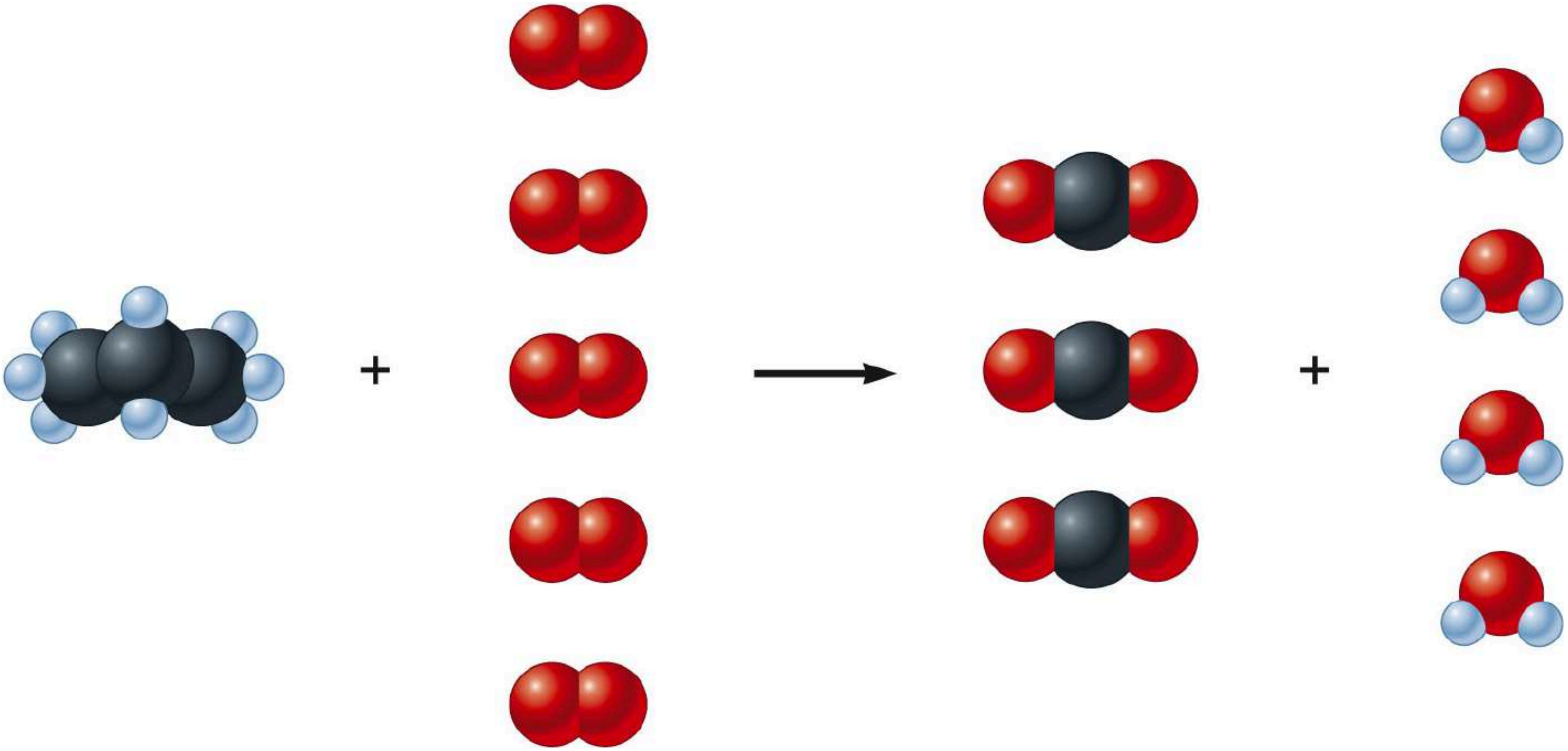


$4H_2O(l)$ $4H_2(g)$ $+$ $2O_2(g)$

2 mol H_2O → yields → 1 mol O_2


5.8 mol H_2O
yields
? mol O_2

Using Chemical Equations




4.30 mol C_3H_8
requires
? mol O_2

Exercise

Consider the following reaction:

$$P_4(s) + 5\,O_2(g) \rightarrow \;{}_2\;\;{}_5\,s$$

If 2.00 moles of phosphorus is burned, how many moles of oxygen does it combine with?

10.0 mol O_2

Objectives

1. To learn to relate masses of reactants and products in a chemical reaction
2. To perform mass calculations that involve scientific notation

A. Mass Calculations

Let's Review

Steps for Calculating the Masses of Reactants and Products in Chemical Reactions

Step 1 Balance the equation for the reaction.

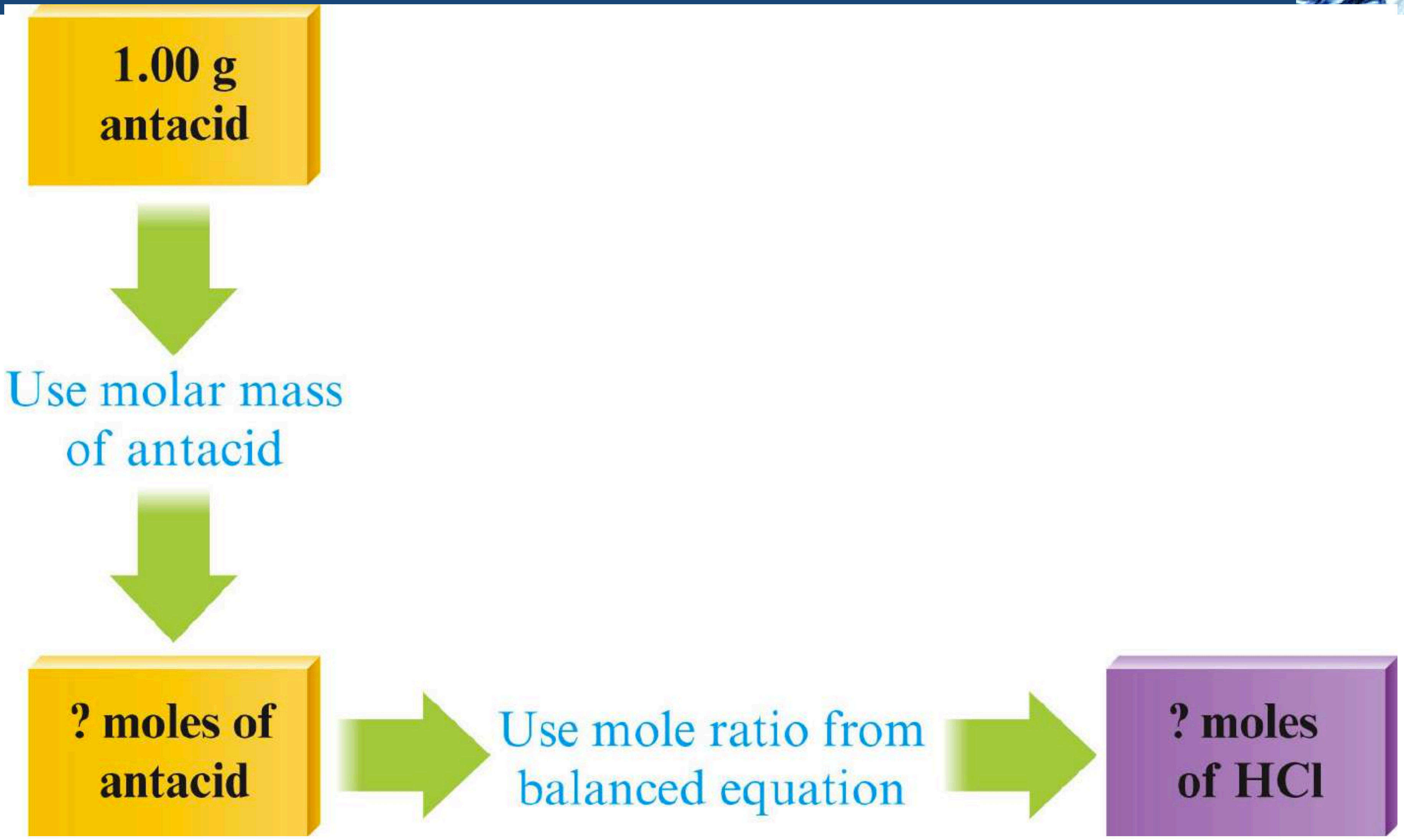
Step 2 Convert the masses of reactants or products to moles.

Step 3 Use the balanced equation to set up the appropriate mole ratio(s).

Step 4 Use the mole ratio(s) to calculate the number of moles of the desired reactant or product.

Step 5 Convert from moles back to mass.

Using Chemical Equations to Calculate Mass



p311

Section 9.2

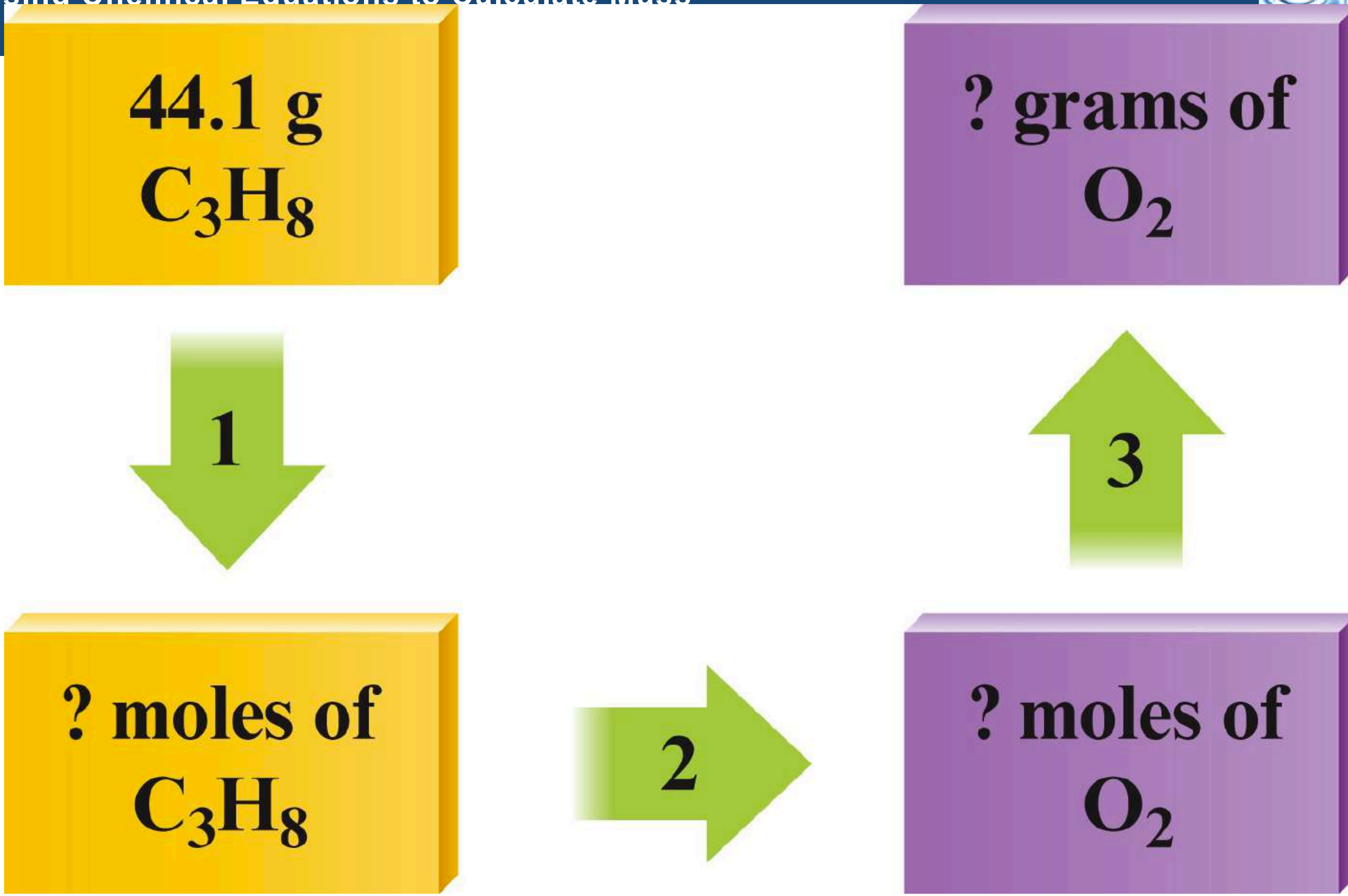
Using Chemical Equations to Calculate Mass

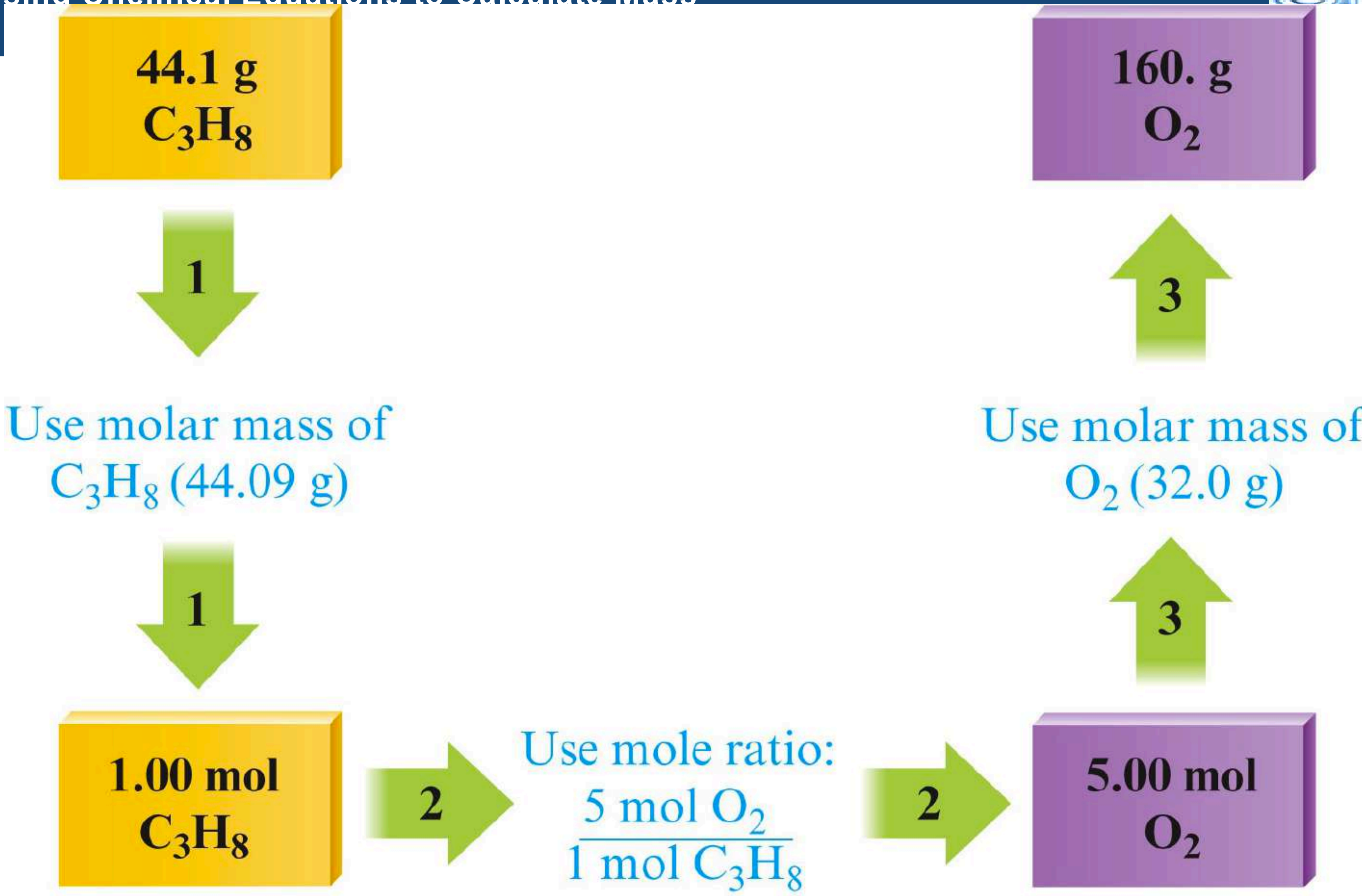
p307

Section 9.2

Using Chemical Equations to Calculate Mass

Using Chemical Equations to Calculate Mass



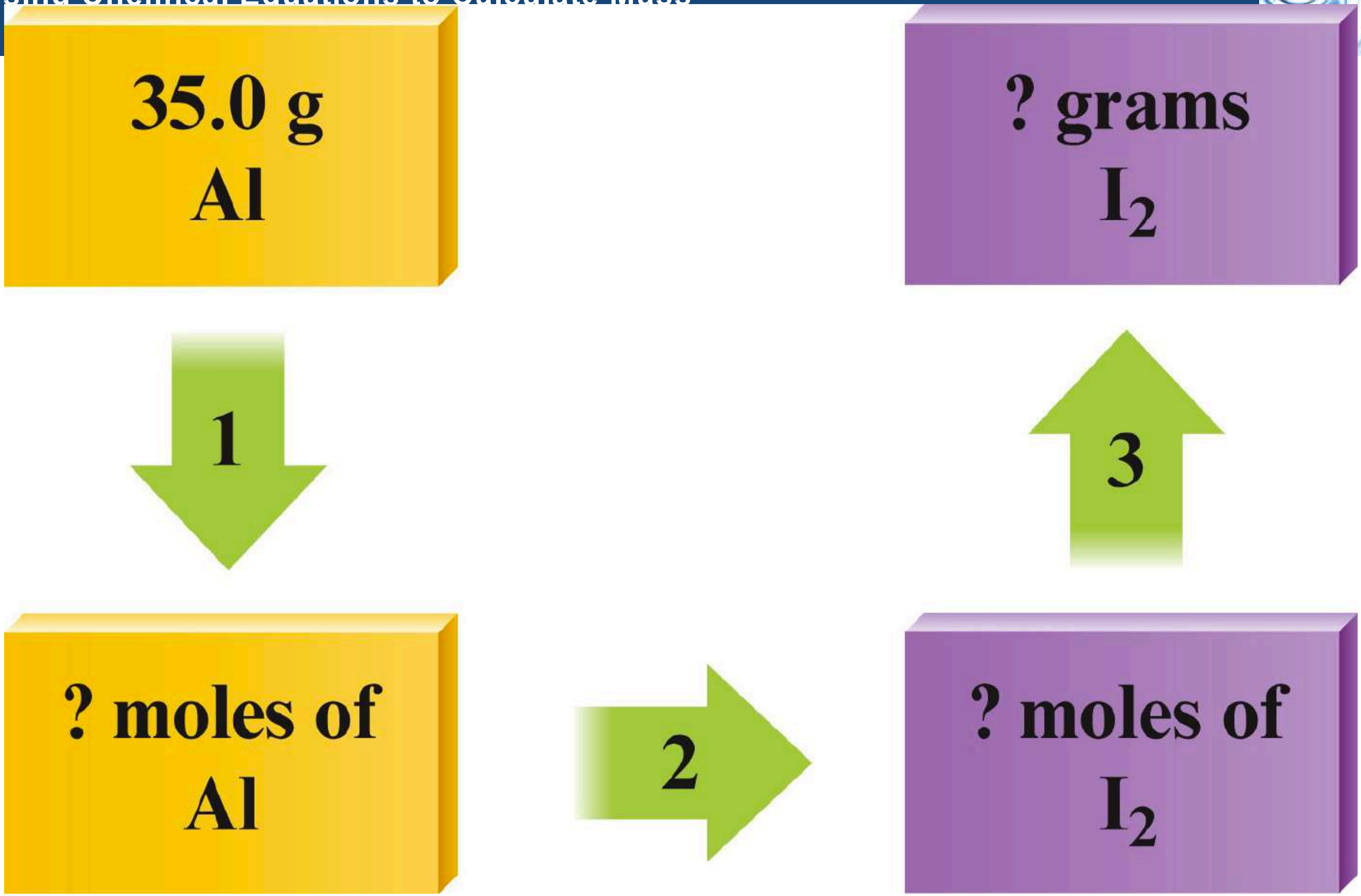

44.1 g
C_3H_8
1
Use molar mass of
C_3H_8 (44.09 g)
1
1.00 mol
C_3H_8
2
Use mole ratio:
$\frac{5 \text{ mol } O_2}{1 \text{ mol } C_3H_8}$
2
5.00 mol
O_2
3
Use molar mass of
O_2 (32.0 g)
3
160. g
O_2

Using Chemical Equations to Calculate Mass

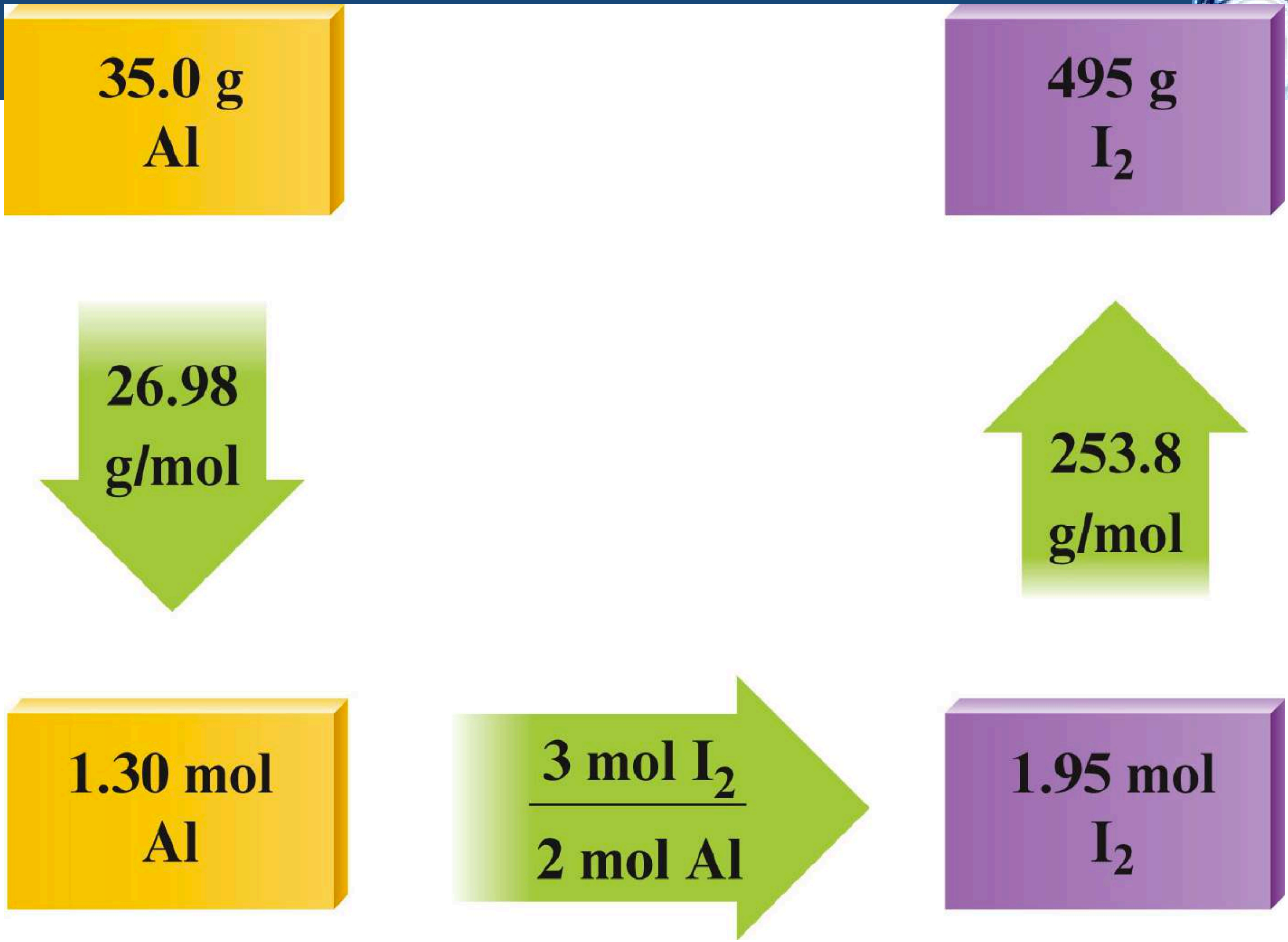
Using Chemica

Using Chemical Equations to Calculate Mass

35.0 g Al(*s*) → **requires** → **? g I_2(*s*)**


35.0 g
Al
1
? moles of
Al
2
? moles of
I2
3
? grams
I2

U


35.0 g Al
26.98 g/mol
1.30 mol Al
3 mol I_2 / 2 mol Al
1.95 mol I_2
253.8 g/mol
495 g I_2

Exercise

Consider the following reaction:

$$P_4(s) + 5\,O_2(g) \longrightarrow \;{}_{2}\;\;{}_{5}\;s$$

If 6.25 g of phosphorus is burned, what mass of oxygen does it combine with?

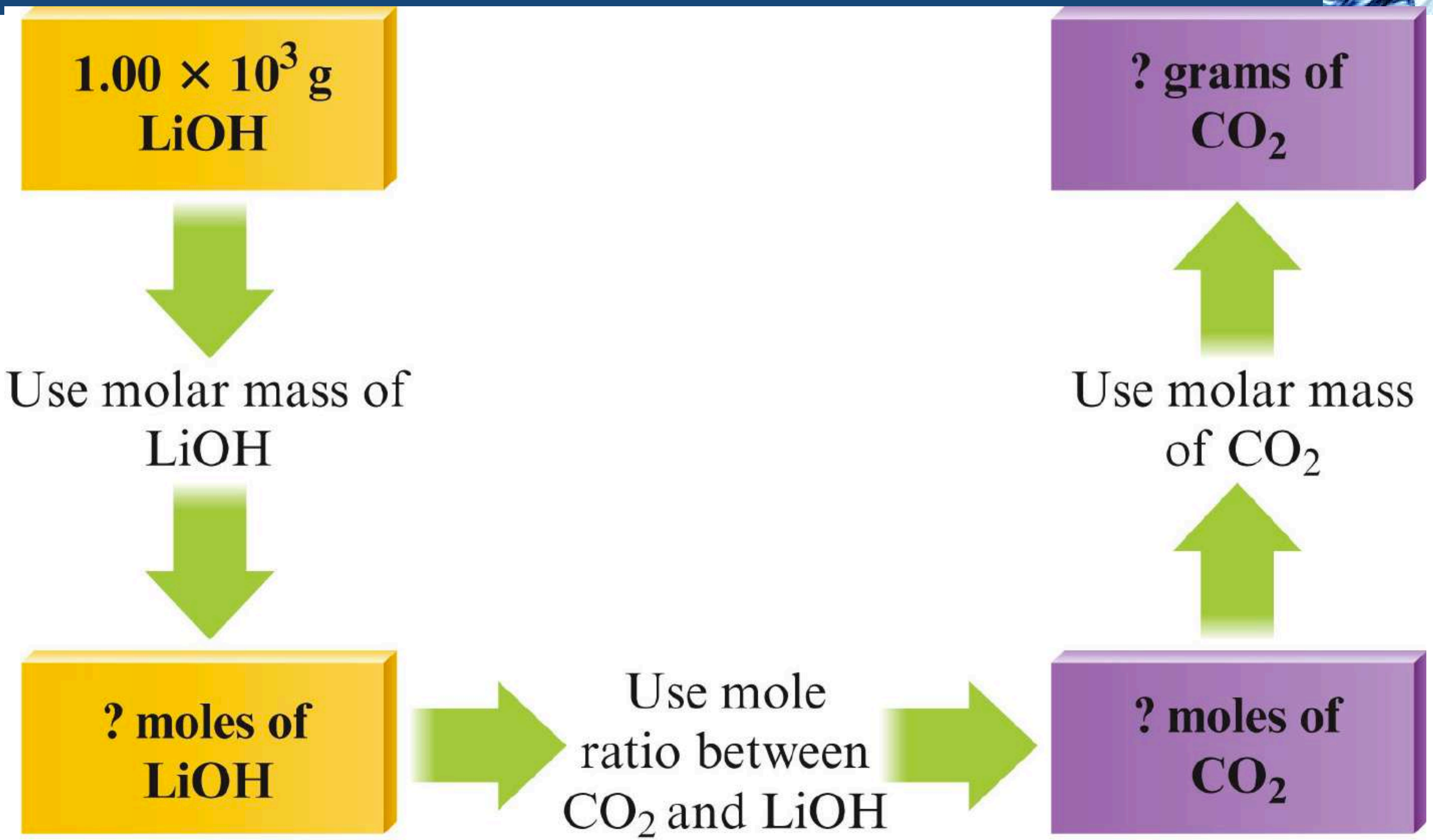
8.07 g O_2

B. Mass Calculations Using Scientific Notation

- Stoichiometry is the process of using a balanced chemical equation to determine the relative masses of reactants and products involved in a reaction.
    - Scientific notation can be used for the masses of any substance in a chemical equation.

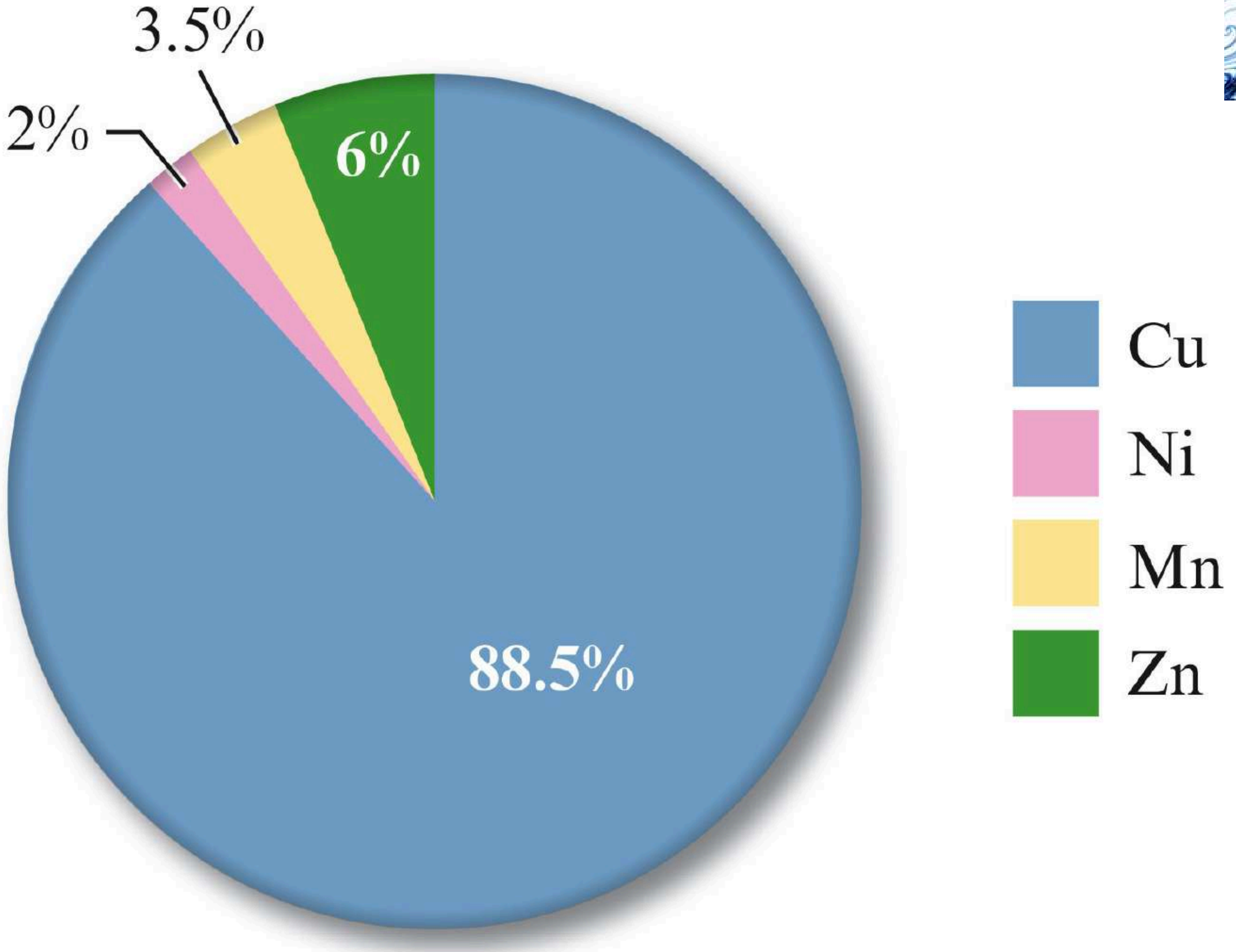
Using Chemical Equations to Calculate Mass

Using Chemical Equations to Calculate Mass




FEDERAL RESERVE NOTE
THE UNITED STATES OF AMERICA
THIS NOTE IS LEGAL TENDER FOR ALL DEBTS, PUBLIC AND PRIVATE
B 07342715 M
WASHINGTON, D.C.
ONE
ONE DOLLAR

Using Chemical Equations to Calculate Mass


3.5%
2%
6%
88.5%
Cu
Ni
Mn
Zn

C. Mass Calculations: Comparing Two Reactions

- To calculate masses from the moles of reactants needed or products formed, we can use the molar masses of substances for finding the masses (g) needed or formed.

Exercise (Part I)

Methane (CH_4) reacts with the oxygen in the air to produce carbon dioxide and water.

Ammonia (NH_3) reacts with the oxygen in the air to produce nitrogen monoxide and water.

- Write balanced equations for each of these reactions.

Exercise (Part II)

Methane (CH_4) reacts with the oxygen in the air to produce carbon dioxide and water.

Ammonia (NH_3) reacts with the oxygen in the air to produce nitrogen monoxide and water.

- What mass of ammonia would produce the same amount of water as 1.00 g of methane reacting with excess oxygen?

Let's Think About It

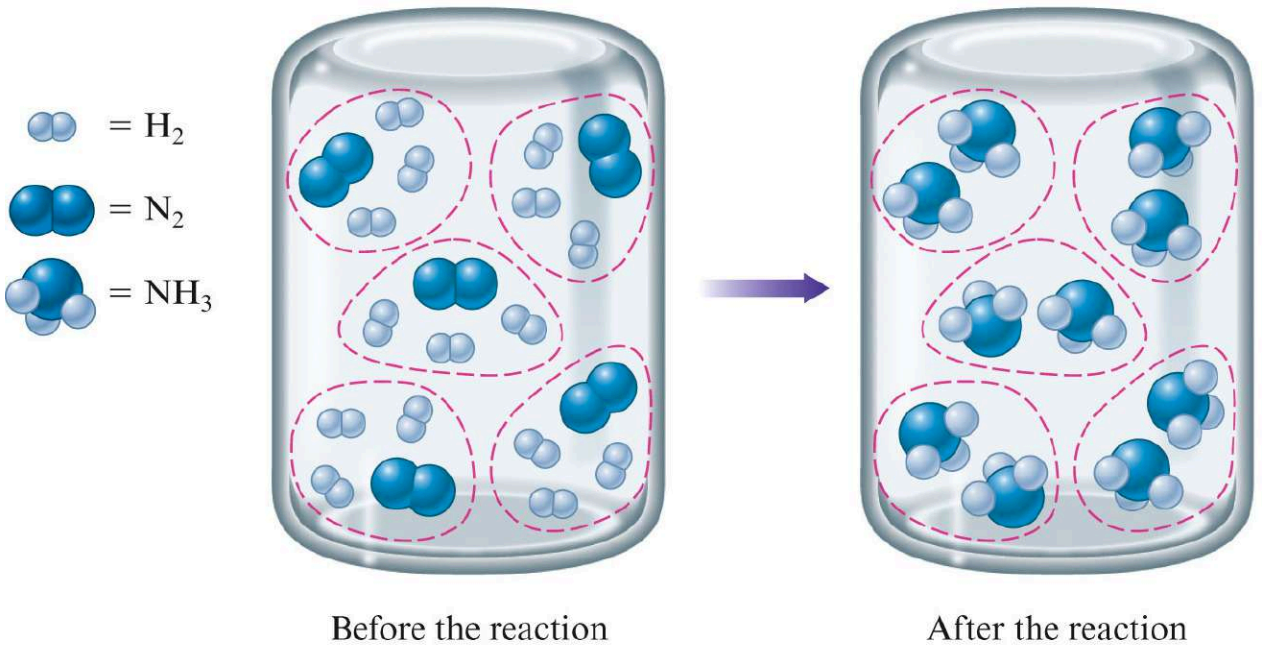
- Where do we want to go?
  - Find the mass of ammonia that would produce the same amount of water as 1.00 g of methane reacting with excess oxygen.
- How do we get there?
  - We need to know:
    - How much water is produced from 1.00 g of methane and excess oxygen.
    - How much ammonia is needed to produce the amount of water calculated above.

Objectives

1. To understand the concept of limiting reactants
2. To learn to recognize the limiting reactant in a reaction
3. To learn to use the limiting reactant to do stoichiometric calculations
4. To learn to calculate percent yield

A. The Concept of Limiting Reactants

- Stoichiometric mixture
  - $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$



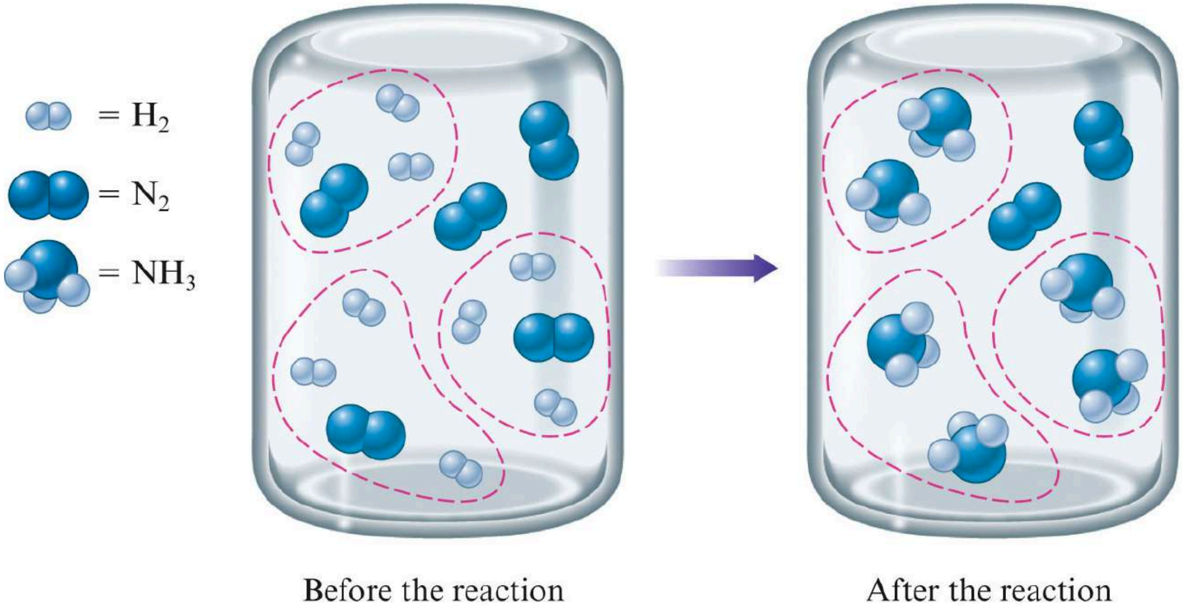
Limiting Reactants and Percent Yield

1.30 mol H_2 → yields → ? mol NH_3

Limiting Reactants and Percent Yield

A. The Concept of Limiting Reactants

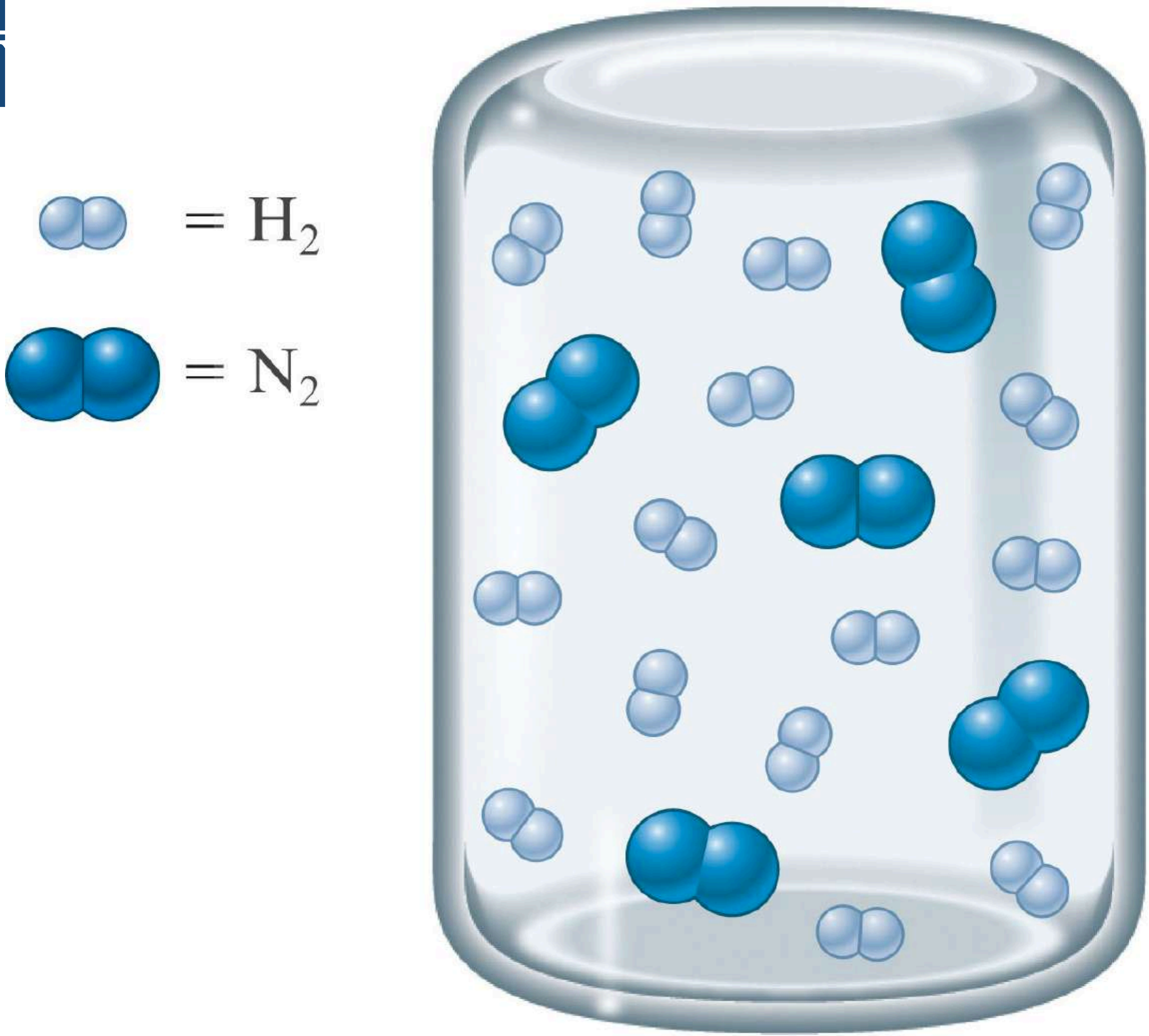
- Limiting reactant mixture
  - $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$



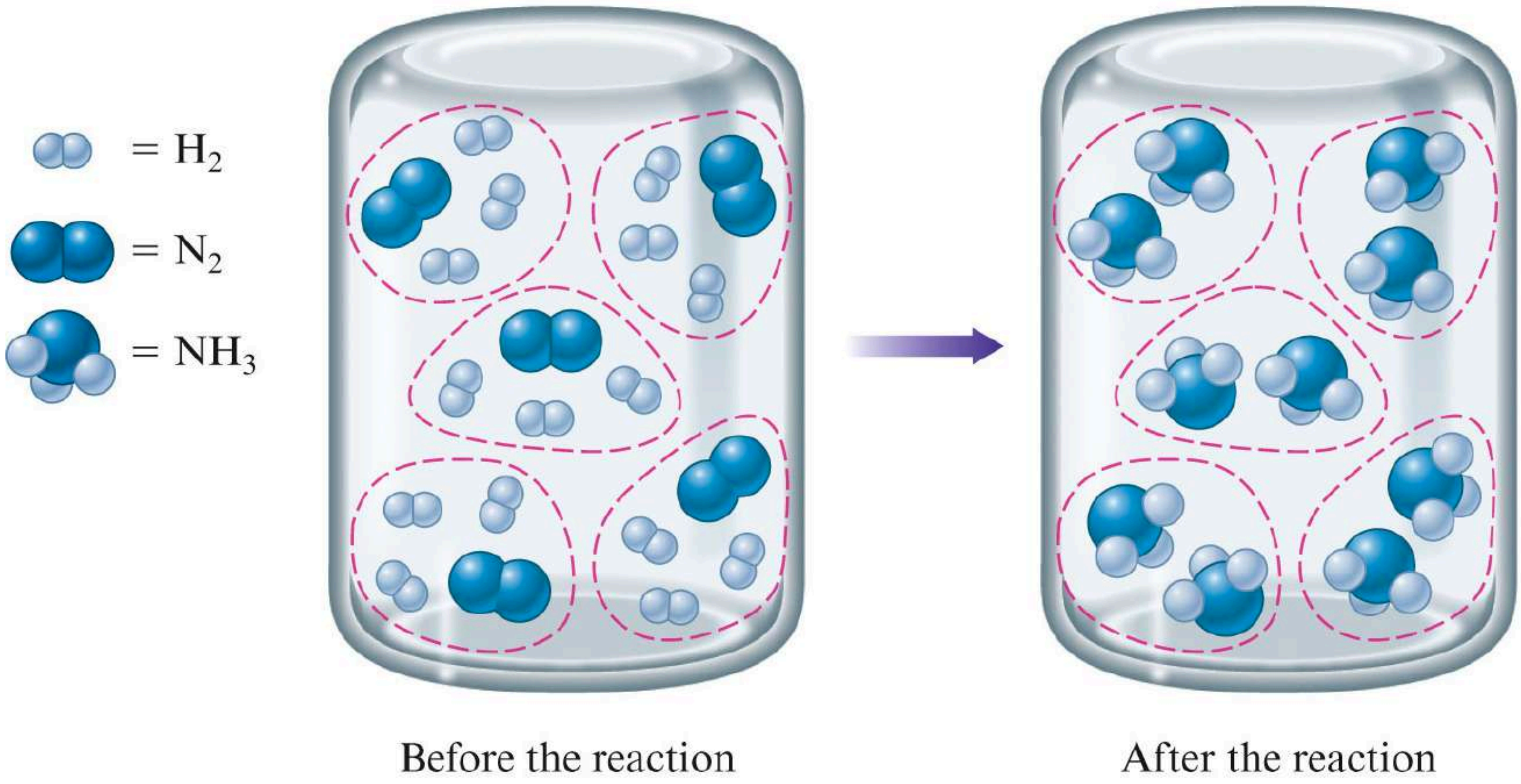
A. The Concept of Limiting Reactants

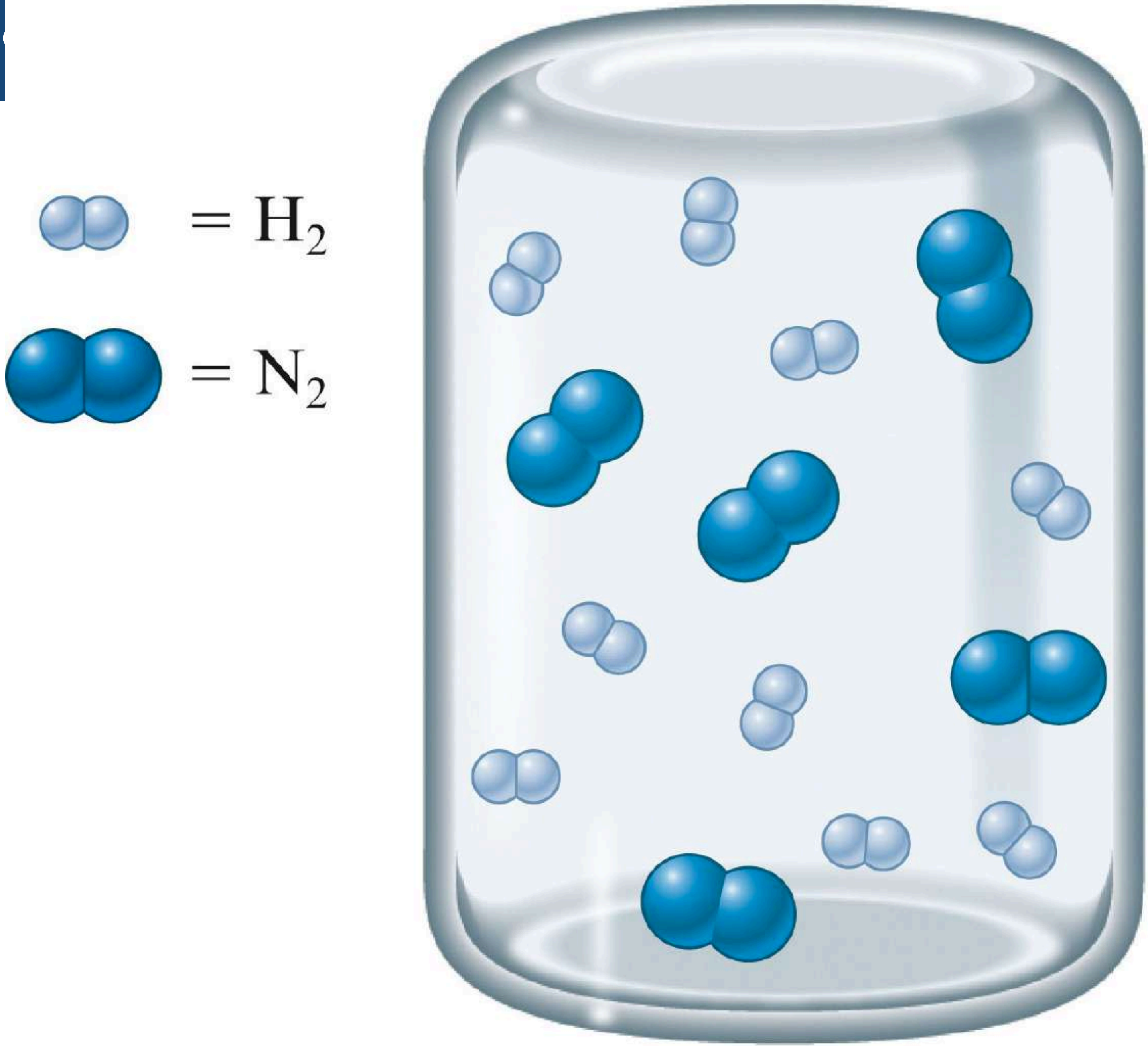
- Limiting reactant mixture
  - $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
  - Limiting reactant is the reactant that runs out first.

H_2

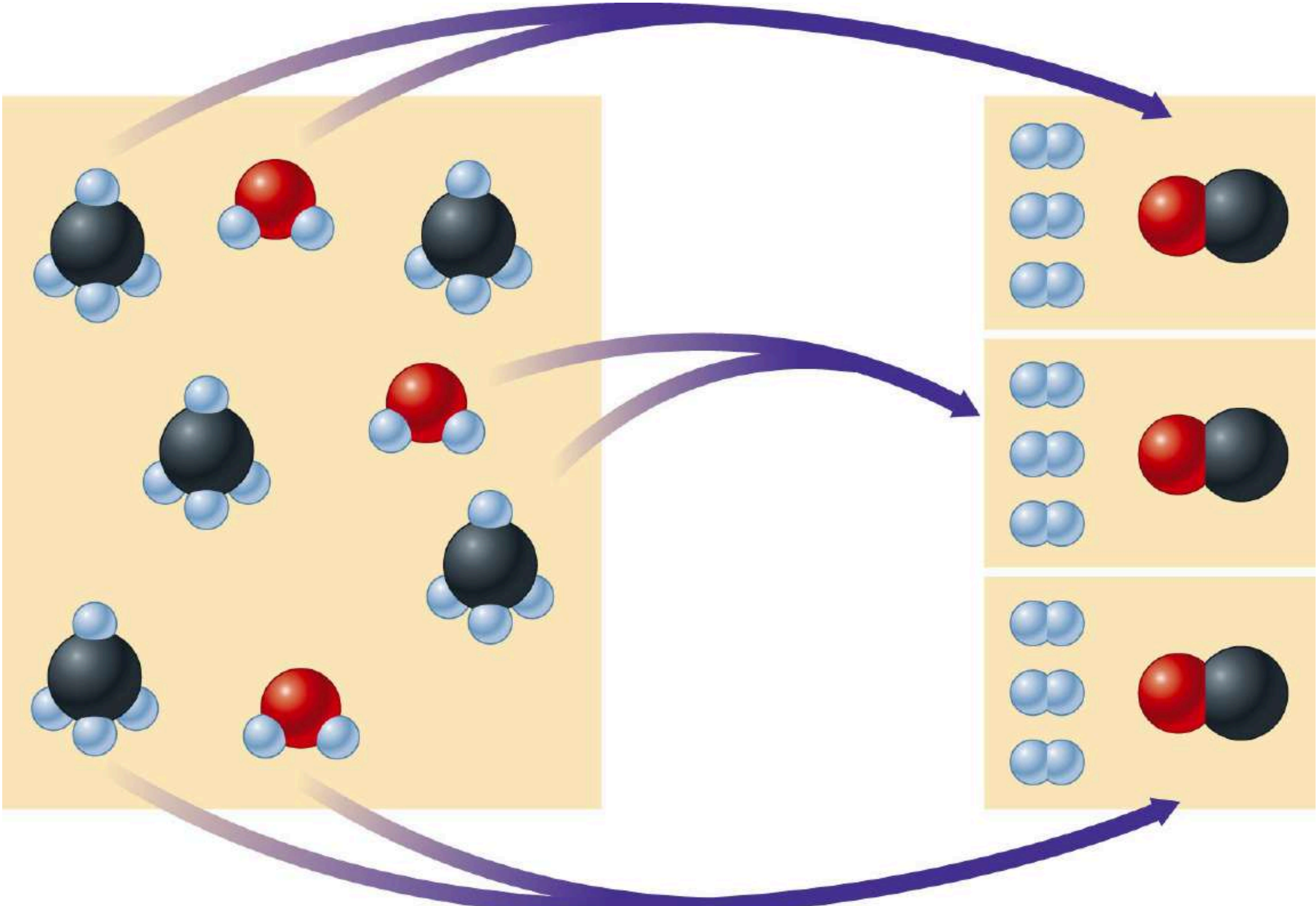

= H_2
= N_2

Limiting Reactants and Percent Yield

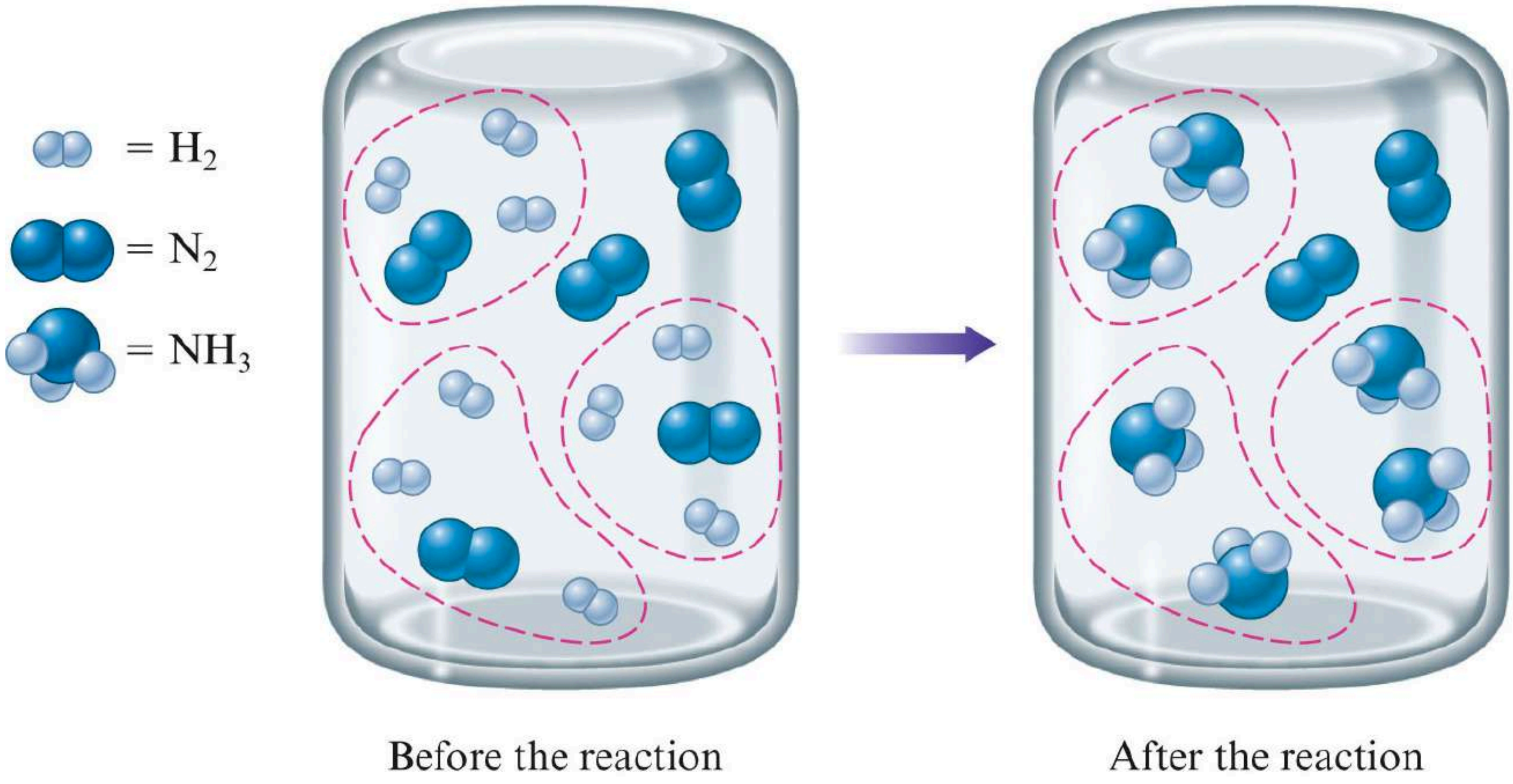



= H_2
= N_2

B. Calculations Involving a Limiting Reactant

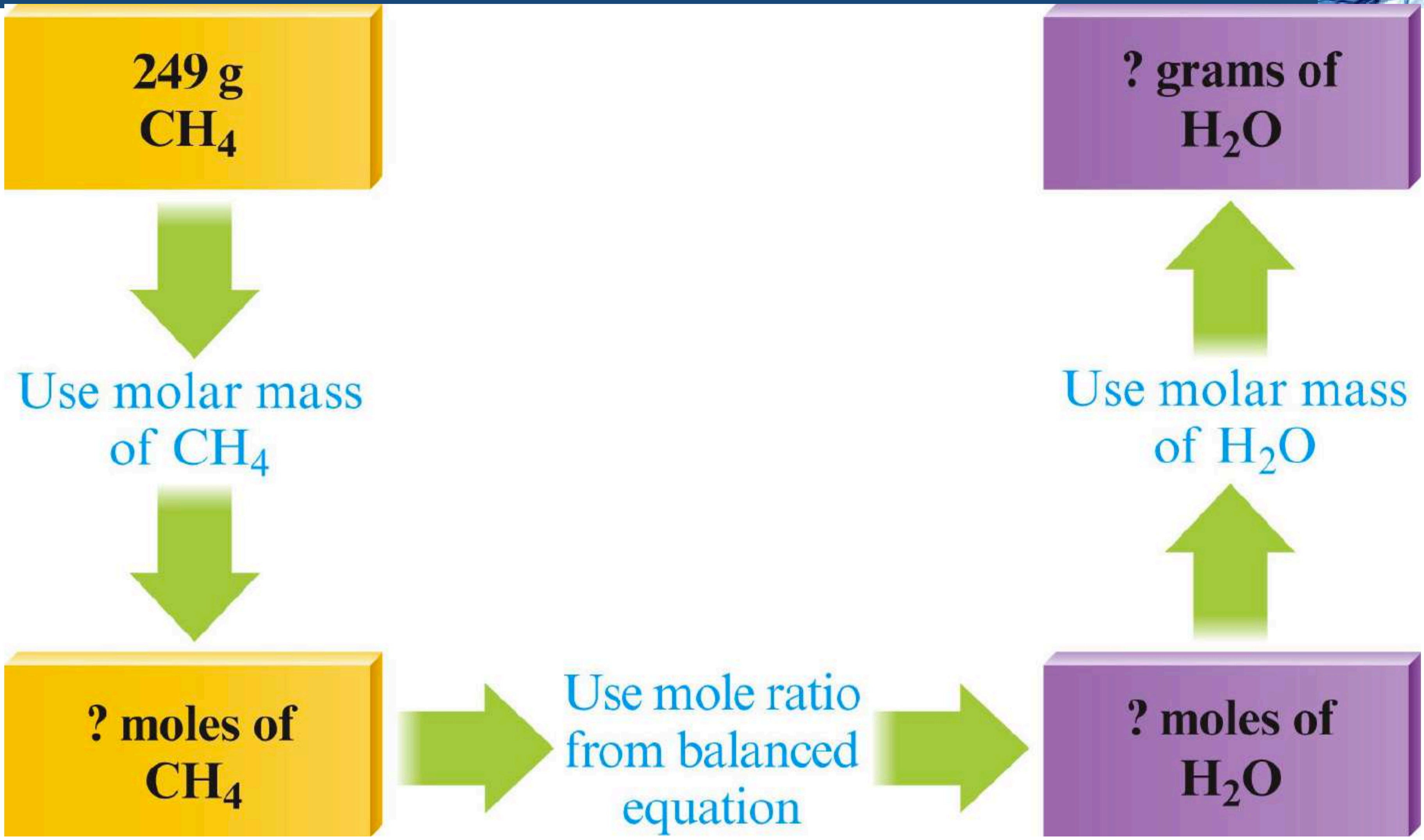


Limiting Reactants and Percent Yield

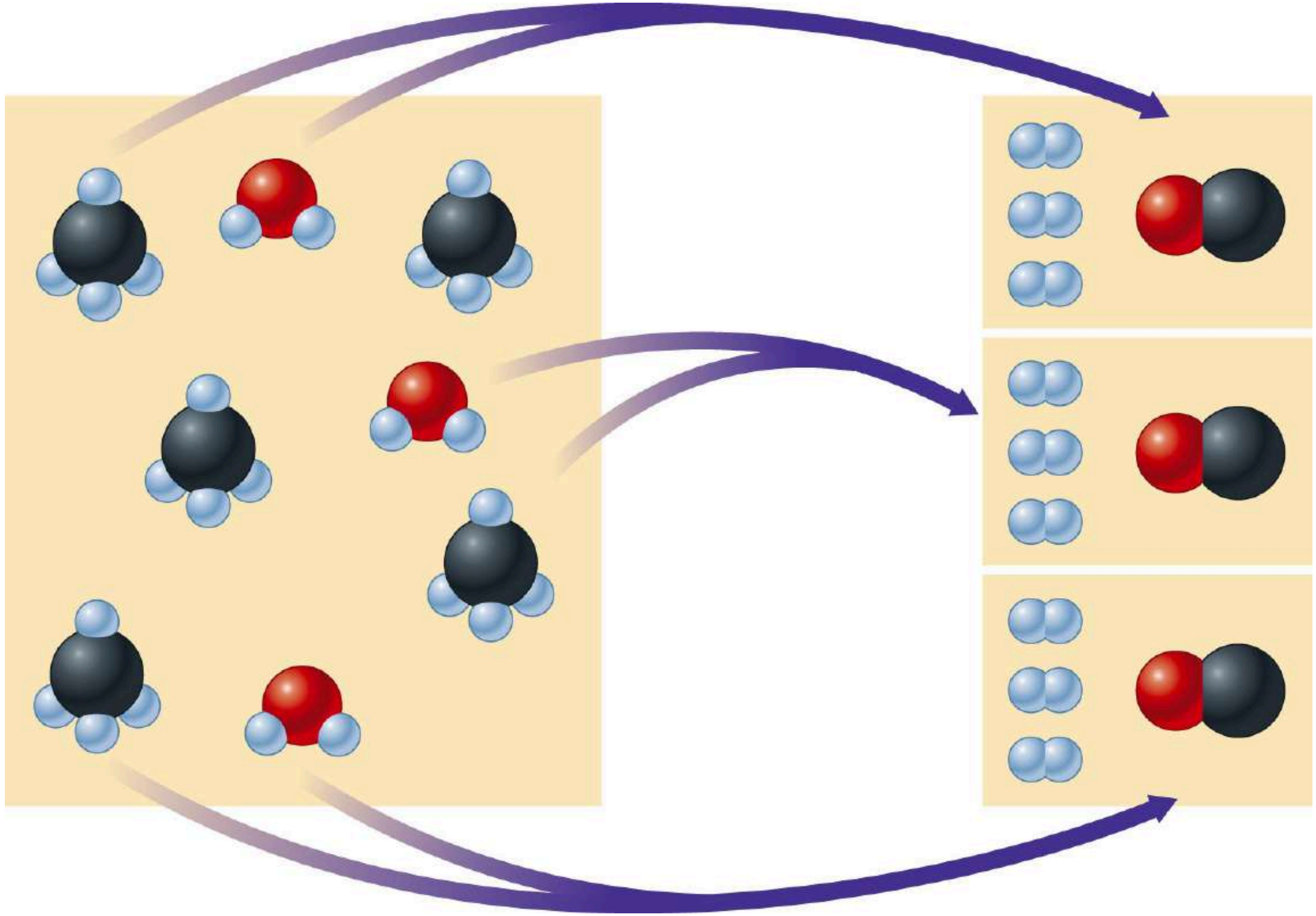


Limiting Reactants and Percent Yield

Limiting Reactants and Percent Yield



B. Calculations Involving a Limiting Reactant



B. Calculations Involving a Limiting Reactant

Let's Review

Steps for Solving Stoichiometry Problems Involving Limiting Reactants

Step 1 Write and balance the equation for the reaction.

Step 2 Convert known masses of reactants to moles.

Step 3 Using the numbers of moles of reactants and the appropriate mole ratios, determine which reactant is limiting.

Step 4 Using the amount of the limiting reactant and the appropriate mole ratios, compute the number of moles of the desired product.

Step 5 Convert from moles of product to grams of product, using the molar mass (if this is required by the problem).

Concept Check

Which of the following reaction mixtures could produce the greatest amount of product? Each involves the reaction symbolized by the equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

a) 2 moles of H_2 and 2 moles of O_2

b) 2 moles of H_2 and 3 moles of O_2

c) 2 moles of H_2 and 1 mole of O_2

d) 3 moles of H_2 and 1 mole of O_2

e) Each produce the same amount of product.

Notice

- We cannot simply add the total moles of all the reactants to decide which reactant mixture makes the most product. We must always think about how much product can be formed by using what we are given, and the ratio in the balanced equation.

Concept Check

- You know that chemical A reacts with chemical B. You react 10.0 g of A with 10.0 g of B.
  - What information do you need to know in order to determine the mass of product that will be produced?

Let's Think About It

- Where do we want to go?
  - Determine the mass of product that will be produced when you react 10.0 g of A with 10.0 g of B.
- How do we get there?
  - We need to know:
    - The mole ratio between A, B, and the product they form. In other words, we need to know the balanced reaction equation.
    - The molar masses of A, B, and the product they form.

Exercise

You react 10.0 g of A with 10.0 g of B. What mass of product will be produced given that the molar mass of A is 10.0 g/mol, B is 20.0 g/mol, and C is 25.0 g/mol? They react according to the equation:

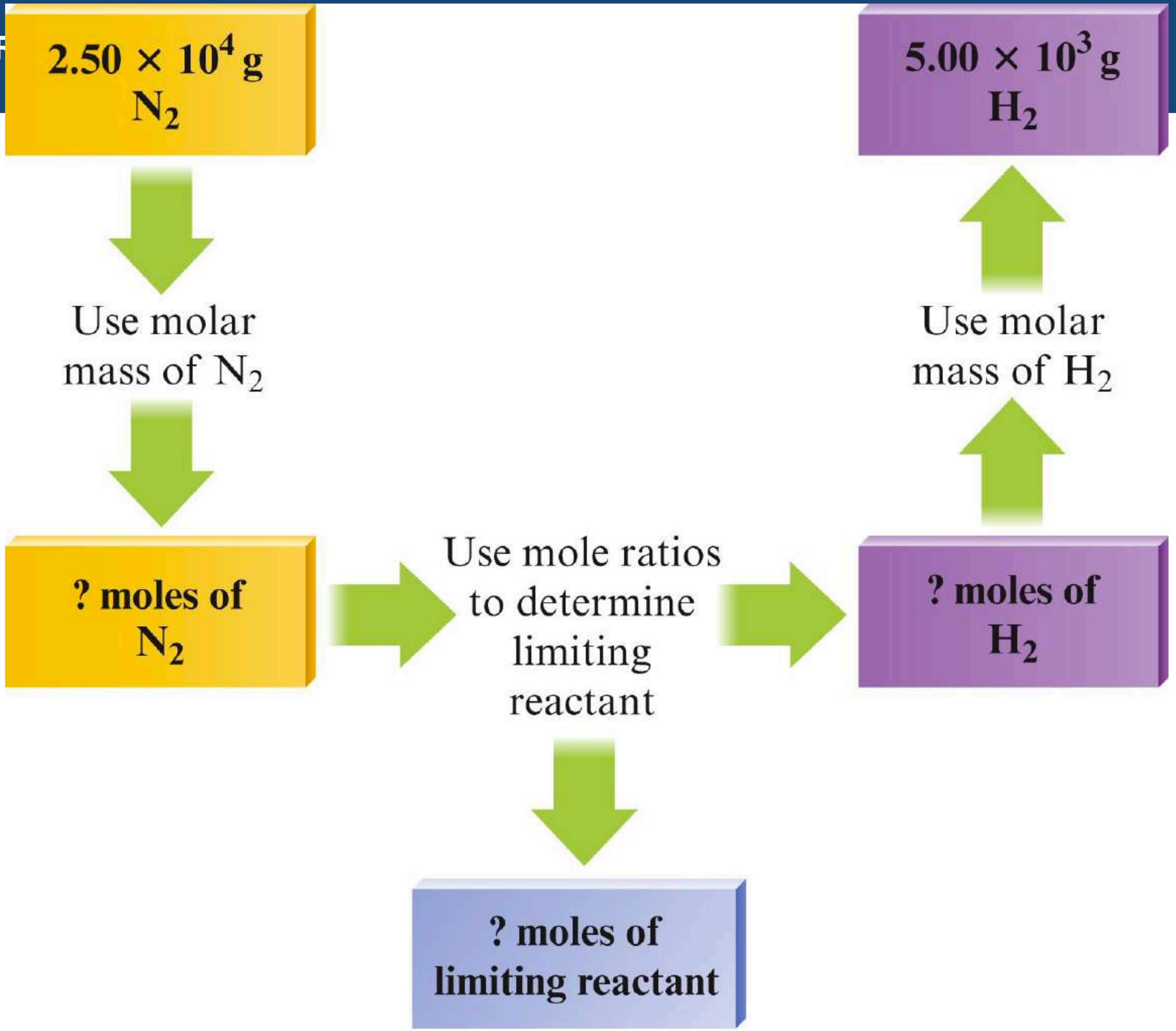
$$A + 3B \rightarrow 2C$$

8.33 g of C is produced.

C. Percent Yield

- Theoretical Yield
  - The maximum amount of a given product that can be formed when the limiting reactant is completely consumed.
- The actual yield (amount produced) of a reaction is usually less than the maximum expected (theoretical yield).
- Percent Yield
  - The actual amount of a given product as the percentage of the theoretical yield.

$$\frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\% = \text{percent yield}$$


2.50 × 10^4 g N2
Use molar mass of N2
? moles of N2
Use mole ratios to determine limiting reactant
? moles of limiting reactant
? moles of H2
Use molar mass of H2
5.00 × 10^3 g H2

Limiting Reactants and Percent Yield

8.92×10^2 mol N_2 → $\dfrac{3 \text{ mol } H_2}{1 \text{ mol } N_2}$ → Moles of H_2 required

Moles of H_2 available		Moles of H_2 required
2.48×10^3	less than	2.68×10^3

Limiting Reactants and Percent Yield

$$2.48 \times 10^3 \text{ mol } H_2 \rightarrow \frac{1 \text{ mol } N_2}{3 \text{ mol } H_2} \rightarrow$$ **Moles of N_2 required**

Moles of N_2 available	greater than	Moles of N_2 required
8.92×10^2	$>$	8.27×10^2

H_2 is limiting reactant.

N_2 is in excess.

Limiting Reactants and Percent Yield

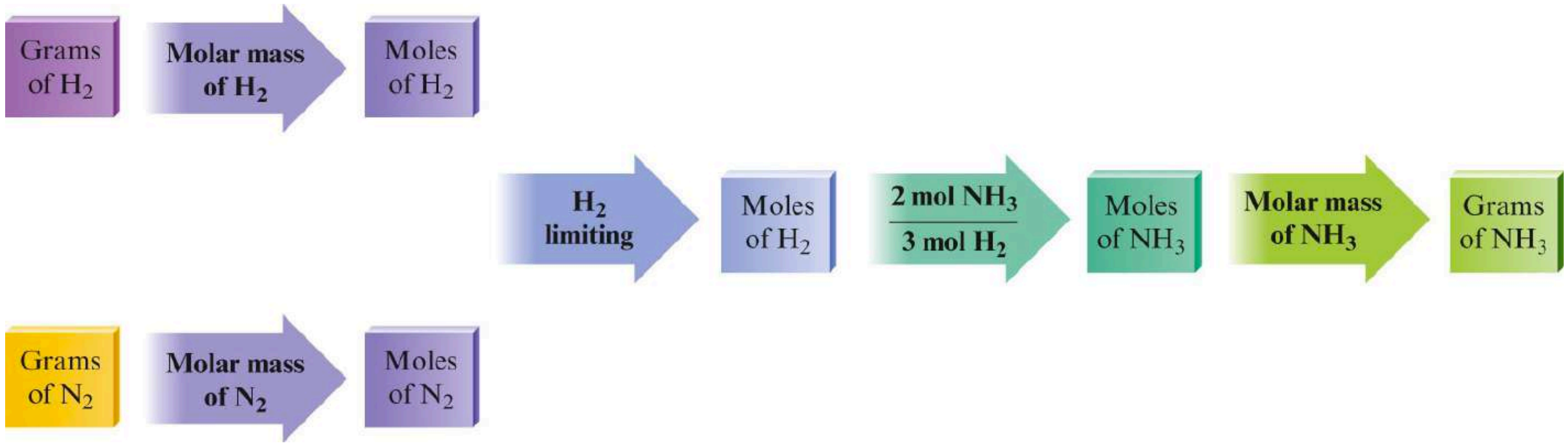
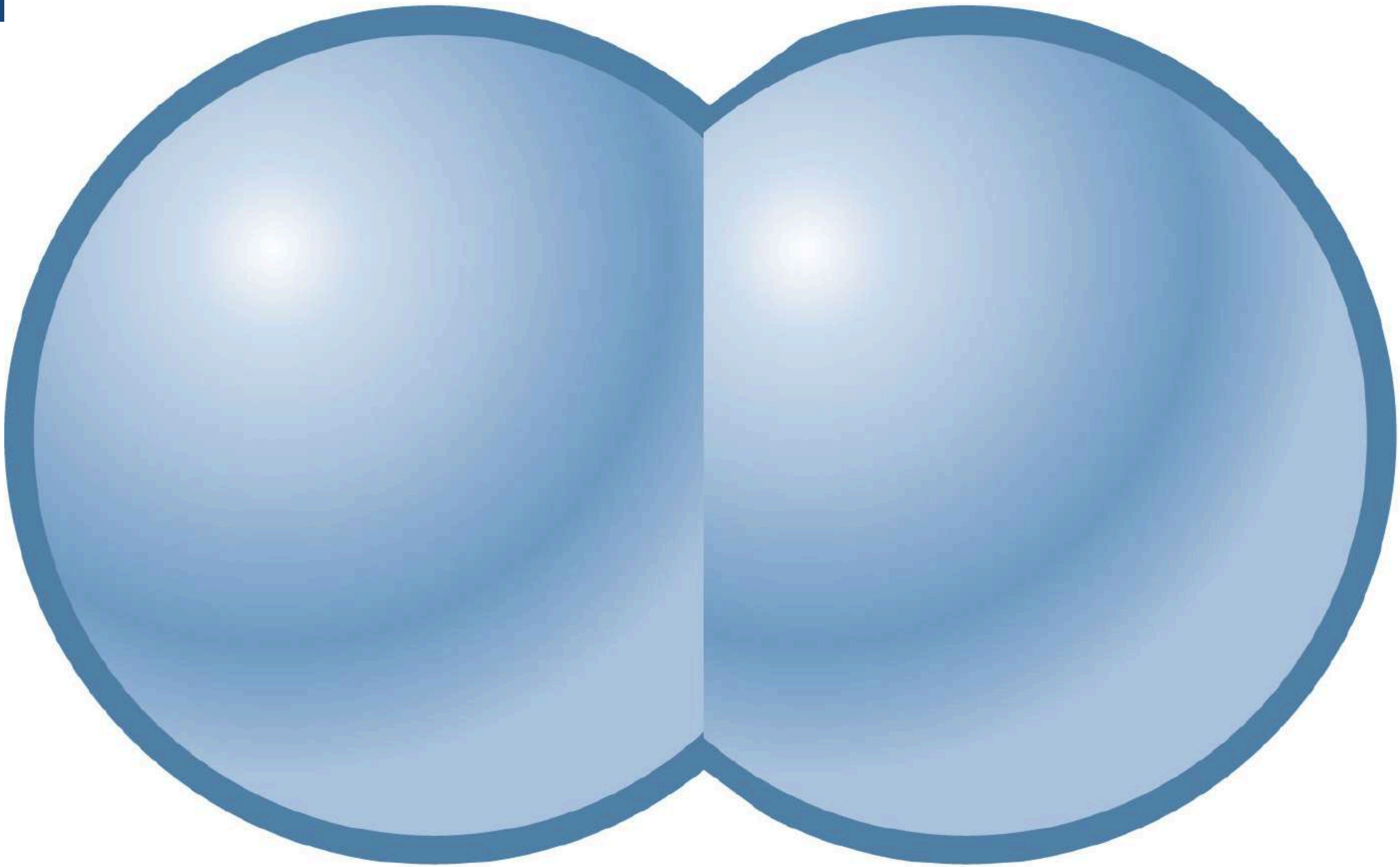


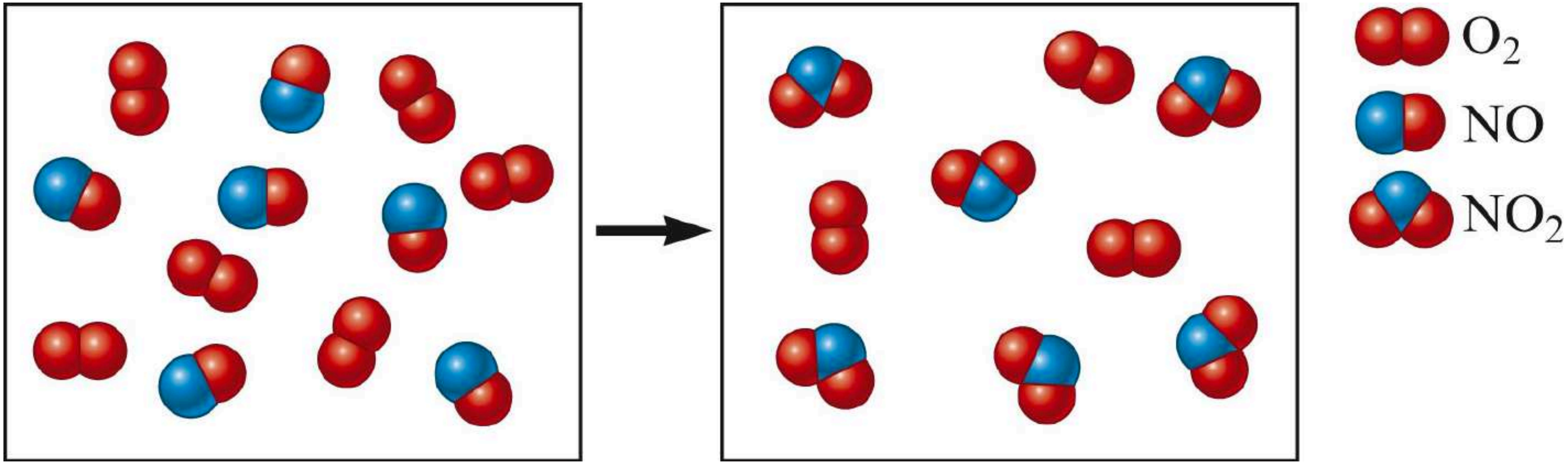
Figure 9-2 p322

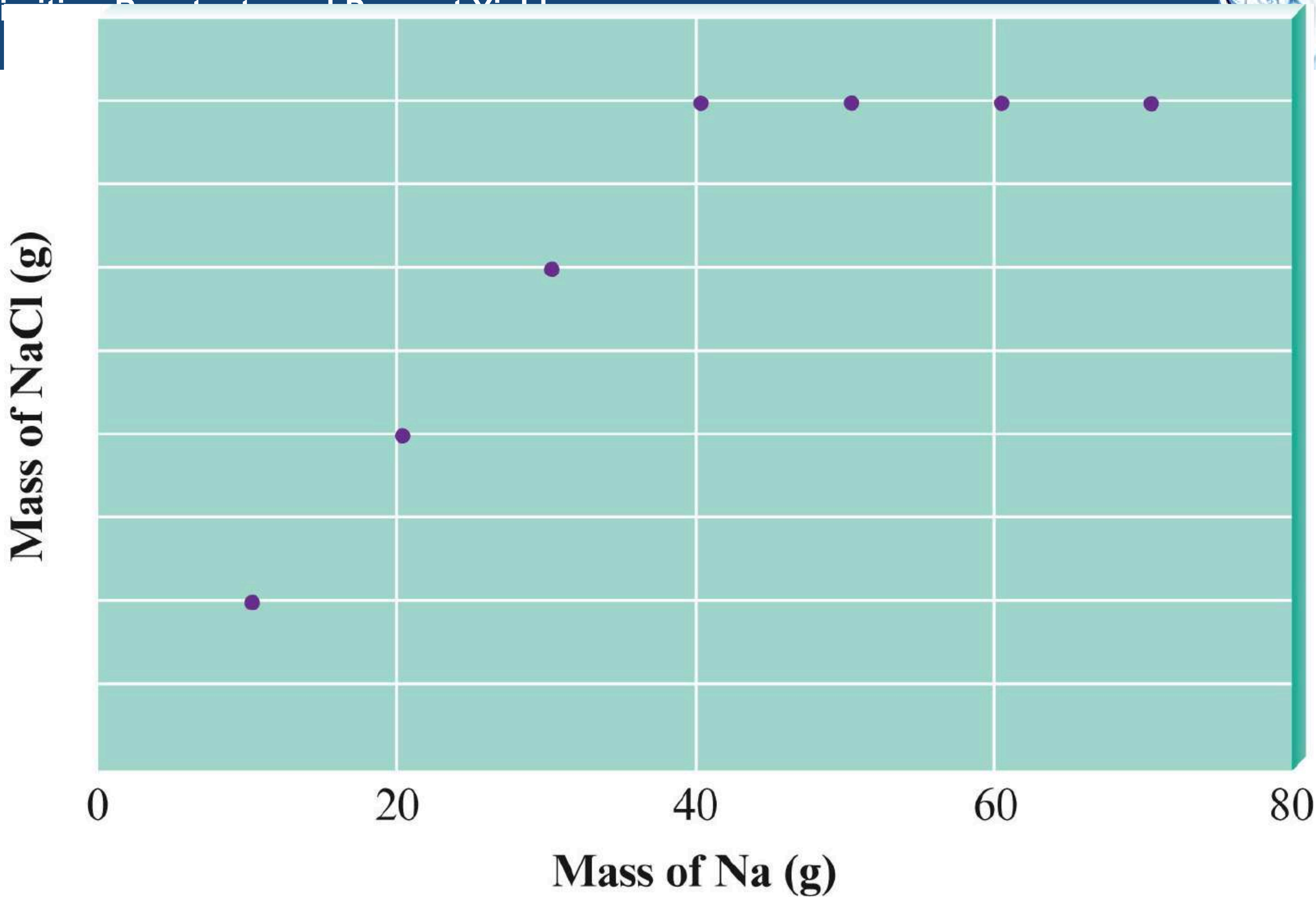
Moles of CuO available	less than	Moles of CuO needed to react with all the NH_3
1.14		1.59

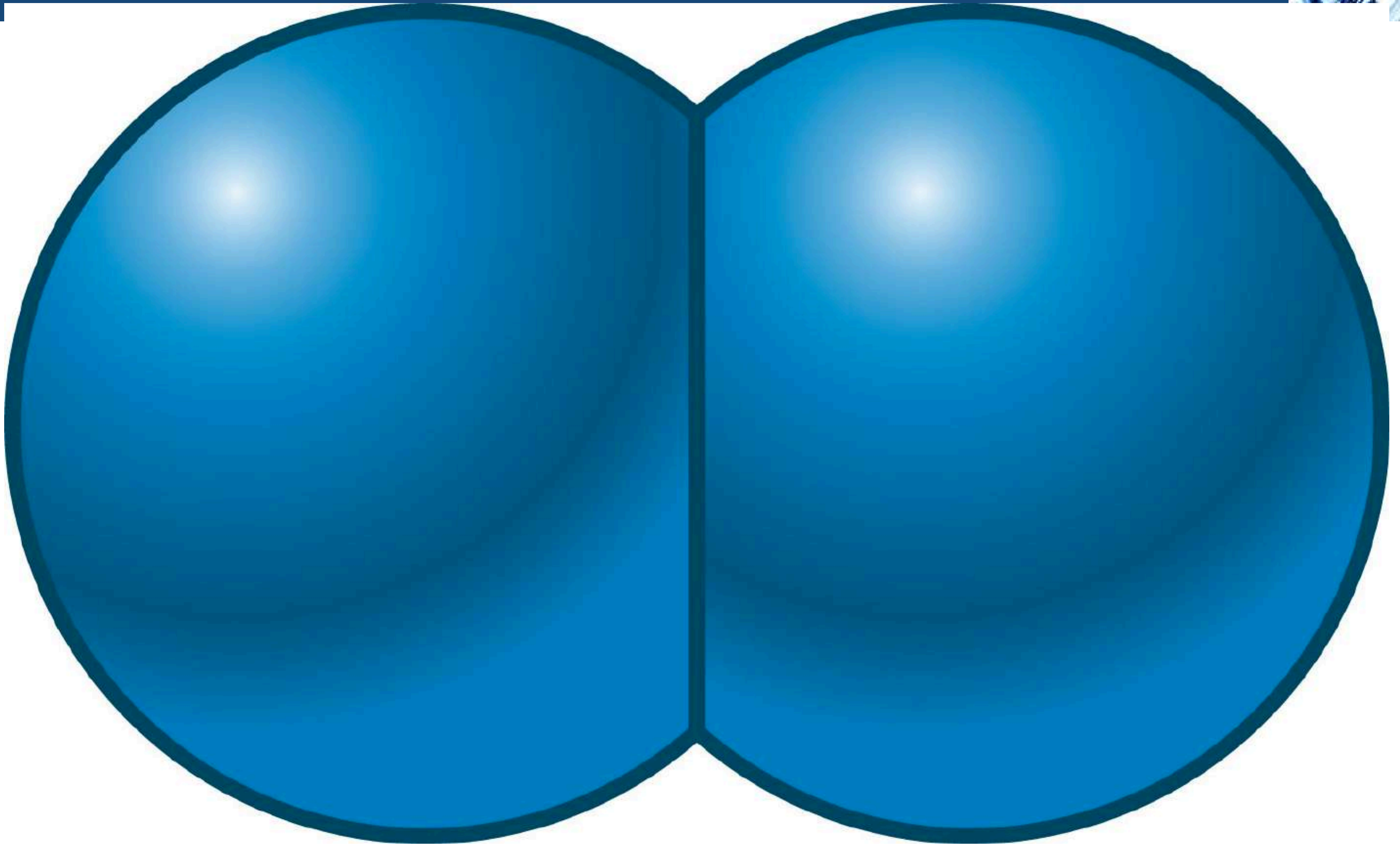
Moles of H_2 present	less than	Moles of H_2 needed to react with all the CO
4.27×10^3		4.90×10^3

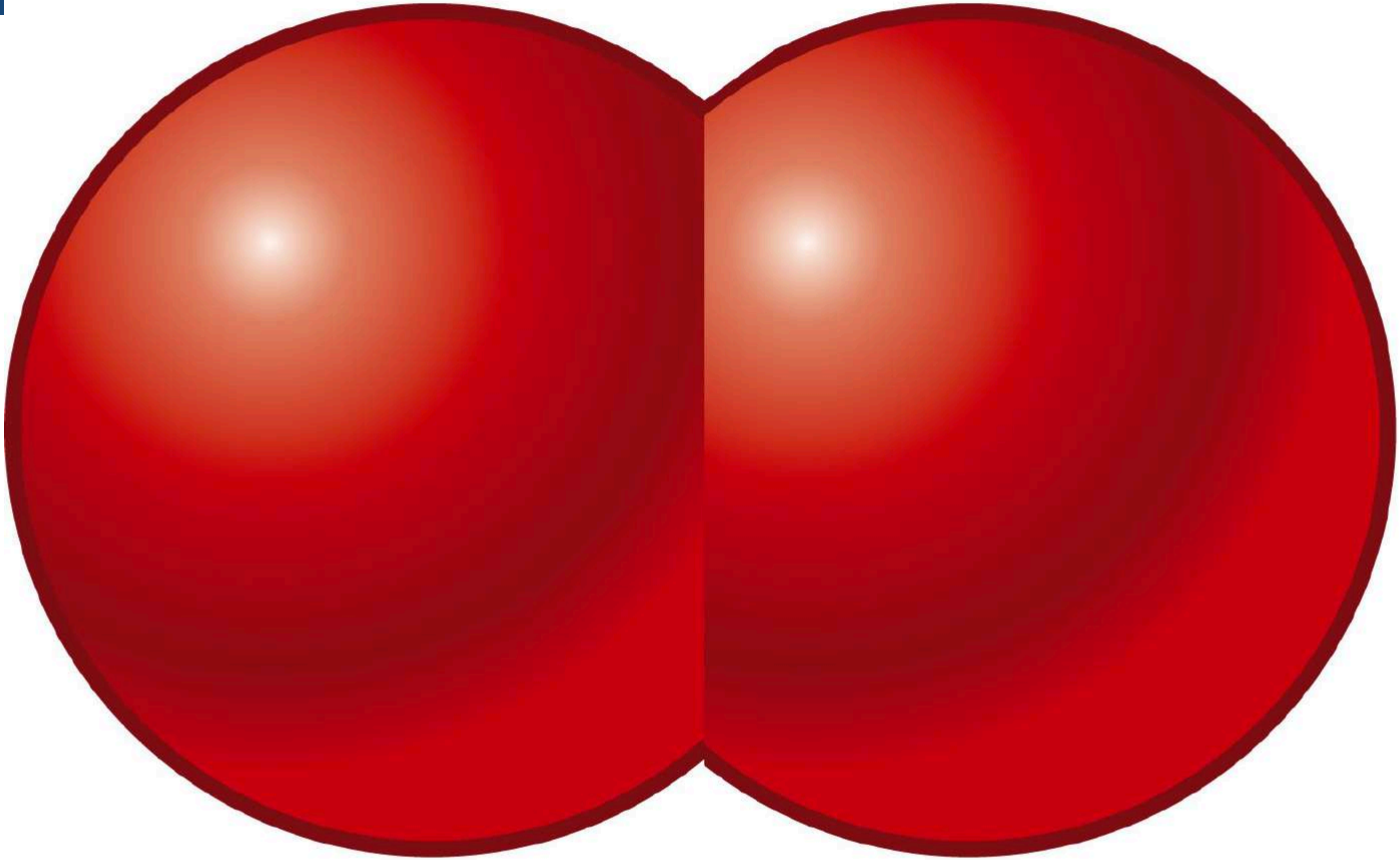


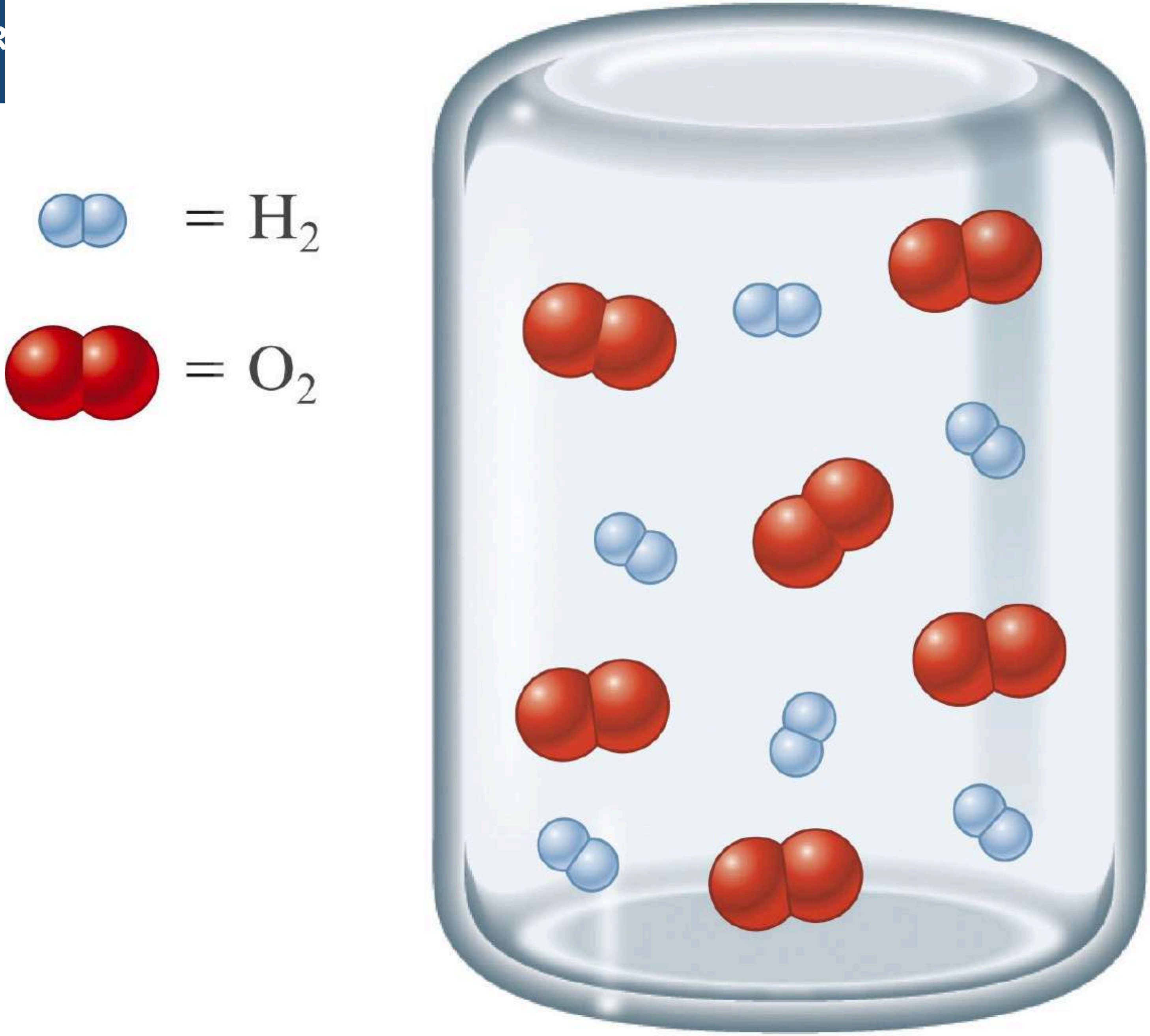
Limiting Reactants and Percent Yield




Mass of NaCl (g)
0
20
40
60
80
Mass of Na (g)






= H_2
= O_2

Exercise

Consider the following reaction:

$$P_4(s) + 6F_2(g) \rightarrow 4PF_3(g)$$

- What mass of P_4 is needed to produce 85.0 g of PF_3 if the reaction has a 64.9% yield?

46.1 g P_4