Chemical Quantities

Chapter 9

Information Given by the Chemical Equation

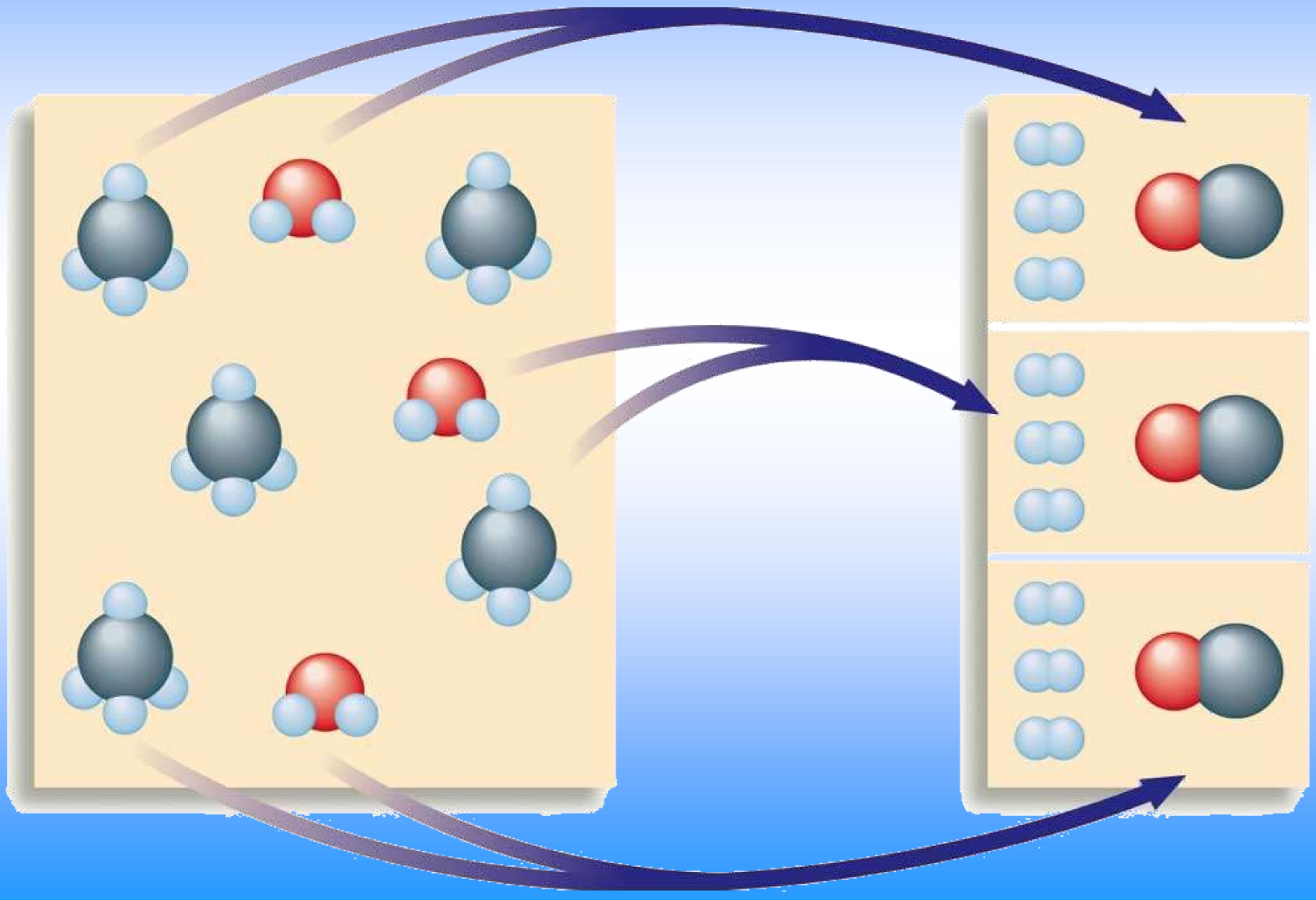
- Balanced equation provides the relationship between the relative numbers of reacting molecules and product molecules

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

2 CO molecules react with 1 O_2 molecules to produce 2 CO_2 molecules

$CO(g)$	+	$2H_2(g)$	→	$CH_3OH(l)$
1 molecule CO	+	2 molecules H_2	→	1 molecule CH_3OH
1 dozen CO molecules	+	2 dozen H_2 molecules	→	1 dozen CH_3OH molecules
6.022×10^{23} CO molecules	+	$2(6.022 \times 10^{23})$ H_2 molecules	→	6.022×10^{23} CH_3OH molecules
1 mol CO molecules	+	2 mol H_2 molecules	→	1 mol CH_3OH molecules

Figure 9.1: A mixture of $5CH_4$ and $3H_2O$ molecules undergoes the reaction $CH_4(g) + H_2O(g) \rightarrow 3H2(g) + CO(g)$.



Information Given by the Chemical Equation

- Since the information given is relative:

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

200 CO molecules react with 100 O_2 molecules to produce 200 CO_2 molecules

2 billion CO molecules react with 1 billion O_2 molecules to produce 2 billion CO_2 molecules

2 moles CO molecules react with 1 mole O_2 molecules to produce 2 moles CO_2 molecules

12 moles CO molecules react with 6 moles O_2 molecules to produce 12 moles CO_2 molecules

Information Given by the Chemical Equation

- **The coefficients in the balanced chemical equation shows the molecules and mole ratio of the reactants and products**
- Since moles can be converted to masses, we can determine the mass ratio of the reactants and products as well

Information Given by the Chemical Equation

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

2 moles CO + 1mole O_2 = 2 moles CO_2

Since 1 mole of CO = 28.01 g, 1 mole O_2 = 32.00 g, and 1 mole CO_2 = 44.01 g

2(28.01) g CO = 1(32.00) g O_2 = 2(44.01) g CO_2

Example #1

Determine the Number of Moles of Carbon Monoxide required to react with 3.2 moles Oxygen, and determine the moles of Carbon Dioxide produced

- Write the balanced equation

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

- Use the coefficients to find the mole relationship

$$2 \text{ moles } CO = 1 \text{ mol } O_2 = 2 \text{ moles } CO_2$$

Example #1

Determine the Number of Moles of Carbon Monoxide required to react with 3.2 moles Oxygen, and determine the moles of Carbon Dioxide produced

- Use dimensional analysis write the balance equation
- $2\ CO + O_2 \rightarrow 2\ CO_2$

$$3.2 \text{ moles } O_2 \text{ x } \frac{2 \text{ moles CO}}{1 \text{ mole } O_2} = 6.4 \text{ moles CO}$$

$$3.2 \text{ moles } O_2 \text{ x } \frac{2 \text{ moles } CO_2}{1 \text{ mole } O_2} = 6.4 \text{ moles } CO_2$$

Example #2

Determine the Number of grams of Carbon Monoxide required to react with 48.0 g Oxygen, and determine the mass of Carbon Dioxide produced

- Write the balanced equation

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

- Use the coefficients to find the mole relationship

$$2 \text{ moles } CO = 1 \text{ mol } O_2 = 2 \text{ moles } CO_2$$

- Determine the Molar Mass of each

$$1 \text{ mol } CO = 28.01 \text{ g}$$

$$1 \text{ mol } O_2 = 32.00 \text{ g}$$

$$1 \text{ mol } CO_2 = 44.01 \text{ g}$$

Example #2

Determine the Number of grams of Carbon Monoxide required to react with 48.0 g Oxygen, and determine the mass of Carbon Dioxide produced

- Use the molar mass of the given quantity to convert it to moles
- Use the mole relationship to convert the moles of the given quantity to the moles of the desired quantity

$$48.0 \text{ g } O_2 \text{ x } \frac{1 \text{ mol } O_2}{32.00 \text{ g}} \text{ x } \frac{2 \text{ mol } CO}{1 \text{ mol } O_2}$$

$$48.0 \text{ g } O_2 \text{ x } \frac{1 \text{ mol } O_2}{32.00 \text{ g}} \text{ x } \frac{2 \text{ mol } CO_2}{1 \text{ mol } O_2}$$

Example #2

Determine the Number of grams of Carbon Monoxide required to react with 48.0 g Oxygen, and determine the mass of Carbon Dioxide produced

± Use the molar mass of the desired quantity to convert the moles to mass

$$48.0\,\text{g}\,O_2 \text{ x } \frac{1\,\text{mol}\,O_2}{32.00\,\text{g}} \text{ x } \frac{2\,\text{mol CO}}{1\,\text{mol}\,O_2} \text{ x } \frac{28.01\,\text{g}}{1\,\text{mol CO}} = 84.0\,\text{g CO}$$

$$48.0\,\text{g}\,O_2 \text{ x } \frac{1\,\text{mol}\,O_2}{32.00\,\text{g}} \text{ x } \frac{2\,\text{mol}\,CO_2}{1\,\text{mol}\,O_2} \text{ x } \frac{44.01\,\text{g}}{1\,\text{mol}\,CO_2} = 132\,\text{g}\,CO_2$$

Limiting and Excess Reactants

- A reactant which is completely consumed when a reaction is run to completion is called a **limiting reactant**
- A reactant which is not completely consumed in a reaction is called an **excess reactant**
  - calculate the amount of excess reactant unused by (1) calculating the amount of excess reactant used from the limiting reactant, then (2) subtract this amount from the amount of excess reactant started with
  - The maximum amount of a product that can be made when the limiting reactant is completely consumed is called the **theoretical yield**

Example #3

Determine the Number of Moles of Carbon Dioxide produced when 3.2 moles Oxygen reacts with 4.0 moles of Carbon Monoxide

- Write the balanced equation

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

- Use the coefficients to find the mole relationship

$$2\ \text{moles}\ CO = 1\ \text{mol}\ O_2 = 2\ \text{moles}\ CO_2$$

Example #3

Determine the Number of Moles of Carbon Dioxide produced when 3.2 moles Oxygen reacts with 4.0 moles of Carbon Monoxide

- Use dimensional analysis to determine the number of moles of reactant A needed to react with reactant B

$$3.2 \text{ moles } O_2 \times \frac{2 \text{ moles CO}}{1 \text{ mole } O_2} = 6.4 \text{ moles CO}$$

Example #3

Determine the Number of Moles of Carbon Dioxide produced when 3.2 moles Oxygen reacts with 4.0 moles of Carbon Monoxide

- Compare the calculated number of moles of reactant A to the number of moles given of reactant A
  - If the calculated moles is greater, then A is the Limiting Reactant; if the calculated moles is less, then A is the Excess Reactant
  - the calculated moles of CO (6.4 moles) is greater than the given 4.0 moles, therefore CO is the **limiting reactant**

Example #3

Determine the Number of Moles of Carbon Dioxide produced when 3.2 moles Oxygen reacts with 4.0 moles of Carbon Monoxide

- Use the limiting reactant to determine the moles of product

$$4.0 \text{ moles CO} \times \frac{2 \text{ moles } CO_2}{2 \text{ mole CO}} = 4.0 \text{ moles } CO_2$$

Example #4

Determine the Mass of Carbon Dioxide produced when 48.0 g of Oxygen reacts with 56.0 g of Carbon Monoxide

- ✶ Write the balanced equation

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

- ✸ Use the coefficients to find the mole relationship

2 moles CO = 1 mol O_2 = 2 moles CO_2

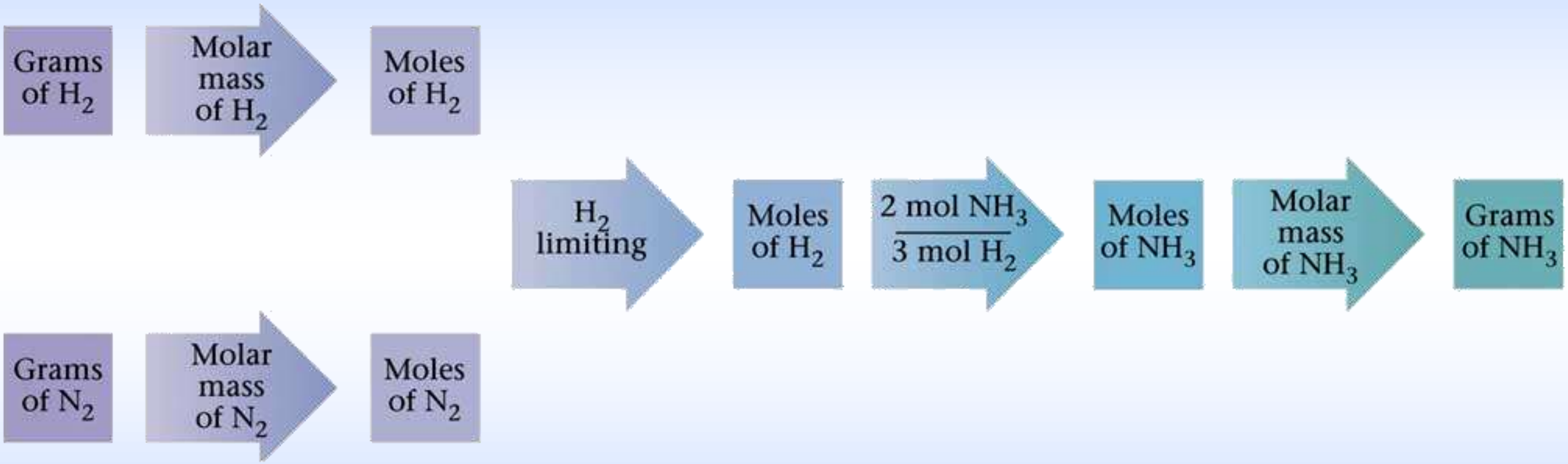
- ✹ Determine the Molar Mass of each

1 mol CO = 28.01 g

1 mol O_2 = 32.00 g

1 mol CO_2 = 44.01 g

Figure 9.2: A map of the procedure used in Example 9.7.



Example #4

Determine the Mass of Carbon Dioxide produced when 48.0 g of Oxygen reacts with 56.0 g of Carbon Monoxide

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

- Determine the moles of each reactant

$$48.0\ g\ O_2 \times \frac{1\ mol\ O_2}{32.00\ g} = 1.50\ moles\ O_2$$

$$56.0\ g\ CO \times \frac{1\ mol\ CO}{28.01\ g} = 2.00\ moles\ CO$$

Example #4

Determine the Mass of Carbon Dioxide produced when 48.0 g of Oxygen reacts with 56.0 g of Carbon Monoxide

- Determine the number of moles of reactant A needed to react with reactant B

$$2.00 \text{ moles CO} \times \frac{1 \text{ moles } O_2}{2 \text{ mole CO}} = 1.00 \text{ moles } O_2$$

Example #4

Determine the Mass of Carbon Dioxide produced when 48.0 g of Oxygen reacts with 56.0 g of Carbon Monoxide

± Compare the calculated number of moles of reactant A to the number of moles given of reactant A
  - If the calculated moles is greater, then A is the Limiting Reactant; if the calculated moles is less, then A is the Excess Reactant
  - the calculated moles of O_2 (1.00 moles) is less than the given 1.50 moles, therefore O_2 is the **excess reactant**

Example #4

Determine the Mass of Carbon Dioxide produced when 48.0 g of Oxygen reacts with 56.0 g of Carbon Monoxide

- Use the limiting reactant to determine the moles of product, then the mass of product

$$2.00 \text{ moles CO} \times \frac{2 \text{ moles } CO_2}{2 \text{ mole CO}} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 88.0 \text{ g } CO_2$$

Percent Yield

- Most reactions do not go to completion
- The amount of product made in an experiment is called the **actual yield**
- The percentage of the theoretical yield that is actually made is called the **percent yield**

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

Example #4a

Determine the Mass of Carbon Dioxide produced when 48.0 g of Oxygen reacts with 56.0 g of Carbon Monoxide If 72.0 g of Carbon Dioxide is actually made, what is the Percentage Yield

- Divide the actual yield by the theoretical yield, then multiply by 100%

The actual yield of CO_2 is 72.0 g

The theoretical yield of CO_2 is 88.0g

$$\frac{72.0\ \text{g}\ CO_2}{88.0\ \text{g}\ CO_2} \times 100\% = 81.8\%$$