Chapter 6

Chemical Calculations: Formula Masses, Moles, and Chemical Equations

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Chapter 6

Chapter Outline

6.1  Formula masses
6.2  The mole: A counting unit for chemists
6.3  The mass of a mole
6.4  Chemical formulas and the mole concept
6.5  The mole and chemical calculations
6.6  Writing and balancing chemical equations
6.7  Chemical equations and the mole concept
6.8  Chemical calculations using chemical equations
6.9  Yields: Theoretical, actual, and percent
• The sum of the atomic masses of all the atoms represented in the chemical formula of a substance

Formula Mass of SnF$_2$ = 156.71 amu

118.71+ (2 × 19.00)
Section 6.1

Formula Masses

What is the formula mass of $\text{H}_2\text{SO}_4$?

a. 49 amu
b. 50 amu
c. 146 amu
d. 98 amu
What is the formula mass of $\text{H}_2\text{SO}_4$?

a. 49 amu  
b. 50 amu  
c. 146 amu  
d. 98 amu
The Mole: A Counting Unit for Chemists

The Mole

• The amount of a substance that contains as many elementary particles (atoms, molecules, or formula units) as there are atoms in exactly 12 grams of $^{12}_6\text{C}$

• 1 mole = $6.02 \times 10^{23}$ objects
How many eggs does one mole of egg contain?

a. 12 eggs  
b. $6.02 \times 10^{23}$ eggs  
c. $6.02 \times 10^{-23}$ eggs  
d. $6.04 \times 10^{23}$ eggs
How many eggs does one mole of egg contain?

a. 12 eggs  
b. $6.02 \times 10^{23}$ eggs  
c. $6.02 \times 10^{-23}$ eggs  
d. $6.04 \times 10^{23}$ eggs
The Mass of a Mole

Molar Mass

• Mass, in grams, of a substance that is numerically equivalent to the formula mass of the substance
  – Molar Mass of N = 14.01 g/mol
  – Molar Mass of CO\(_2\) = 44.01 g/mol
  \[12.01 + (2 \times 16)\]
Exercise

• Calculate the mass, in grams, of a 2.5 mole sample of ethane, C₂H₆
Exercise

• Calculate the mass, in grams, of a 2.5 mole sample of ethane, $\text{C}_2\text{H}_6$

$$2.5 \text{ mol C}_2\text{H}_6 \times \left( \frac{30.07 \text{ g C}_2\text{H}_6}{1 \text{ mol C}_2\text{H}_6} \right)$$
Exercise

• Calculate the mass, in grams, of a 2.5 mole sample of ethane, $C_2H_6$

\[
2.5 \text{ mol } C_2H_6 \times \left( \frac{30.07 \text{ g } C_2H_6}{1 \text{ mol } C_2H_6} \right) = 75 \text{ g } C_2H_6
\]
Section 6.3

The Mass of a Mole

Exercise

• Calculate the number of moles in 50.0 g of H₂O
Exercise

- Calculate the number of moles in 50.0 g of H$_2$O

$$\frac{50.0 \text{ g H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{1 \text{ mol H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 2.78 \text{ mol H}_2\text{O}$$
Exercise

• Calculate the number of moles in 50.0 g of H₂O

\[
50.0 \text{ g } H_2O \times \left( \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \right) = 2.78 \text{ mol } H_2O
\]

2.78 mol H₂O
Aspirin has a molecular formula of $\text{C}_9\text{H}_8\text{O}_4$. What is the mass of 1 mole of aspirin?

a. 325 mg  
b. 85 mg  
c. 180 g  
d. 200 mg
Aspirin has a molecular formula of $\text{C}_9\text{H}_8\text{O}_4$. what is the mass of 1 mole of aspirin?

a. 325 mg  
b. 85 mg  
c. 180 g  
d. 200 mg
Section 6.4

Chemical Formulas and the Mole Concept

Chemical Formula - A Microscopic View

• The numerical subscripts in a chemical formula give the number of atoms of the various elements present in 1 formula unit of the substance
  – In one molecule of $\text{N}_2\text{O}_4$, two atoms of nitrogen and four atoms of oxygen are present
Chemical Formulas and the Mole Concept

Chemical Formula - A Macroscopic View

• A chemical formula indicates the number of moles of atoms of each element present in one mole of a substance
  – In one mole of $\text{N}_2\text{O}_4$, two moles of nitrogen atoms and four moles of oxygen atoms are present
Chemical Formulas and the Mole Concept

Exercise

• How many moles of carbon atoms and hydrogen atoms are present in a 2.5 mole sample of ethane, C₂H₆?
Section 6.4
Chemical Formulas and the Mole Concept

Exercise

• How many moles of carbon atoms and hydrogen atoms are present in a 2.5 mole sample of ethane, C₂H₆?

\[
\text{2.5 mol C}_2\text{H}_6 \times \left( \frac{2 \text{ mol C}}{1 \text{ mol C}_2\text{H}_6} \right) = 5.0 \text{ mol C atoms}
\]

\[
\text{2.5 mol C}_2\text{H}_6 \times \left( \frac{6 \text{ mol H}}{1 \text{ mol C}_2\text{H}_6} \right) = 15 \text{ mol H atoms}
\]
In the molecular formula of aspirin, $\text{C}_9\text{H}_8\text{O}_4$, how many moles of carbon atoms, hydrogen atoms, and oxygen atoms are present?

a. 9; 8; 4
b. $2.72 \times 10^{24}$; $4.82 \times 10^{24}$; $2.41 \times 10^{24}$
c. $6.02 \times 10^{23}$ of each
d. 1; 1; 1
In the molecular formula of aspirin, $\text{C}_9\text{H}_8\text{O}_4$, how many moles of carbon atoms, hydrogen atoms, and oxygen atoms are present?

- **a.** 9; 8; 4
- **b.** $2.72 \times 10^{24}$; $4.82 \times 10^{24}$; $2.41 \times 10^{24}$
- **c.** $6.02 \times 10^{23}$ of each
- **d.** 1; 1; 1
Figure 6.9 - Conversion Factors for Solving Chemical-Formula-Based Problems
Concept Check

- Which of the following is closest to the average mass of one atom of copper?

a. 63.55 g
b. 52.00 g
c. 58.93 g
d. 65.38 g
e. $1.055 \times 10^{-22}$ g
Concept Check

• Which of the following is closest to the average mass of one atom of copper?

a. 63.55 g
b. 52.00 g
c. 58.93 g
d. 65.38 g
e. $1.055 \times 10^{-22}$ g
Concept Check

• Calculate the number of copper atoms in a 63.55 g sample of copper
Concept Check

- Calculate the number of copper atoms in a 63.55 g sample of copper

$$6.022 \times 10^{23} \text{ Cu atoms}$$
Concept Check

• Which of the following 100.0 g samples contains the greatest number of atoms?

a. Magnesium
b. Zinc
c. Silver
Concept Check

- Which of the following 100.0 g samples contains the greatest number of atoms?

a. Magnesium
b. Zinc
c. Silver
Exercise

• Rank the following according to their **descending number of atoms**

a. 107.9 g of silver
b. 70.0 g of zinc
c. 21.0 g of magnesium
Exercise

• Rank the following according to their **descending number of atoms**

a. 107.9 g of silver  b. 70.0 g of zinc  
   c. 21.0 g of magnesium  
   
   b. 70.0 g of zinc  a. 107.9 g of silver  
   c. 21.0 g of magnesium
Exercise

• Consider separate 100.0 g samples of each of the following:

\[ \text{H}_2\text{O, N}_2\text{O, C}_3\text{H}_6\text{O}_2, \text{CO}_2 \]

– Rank them in **descending order** of number of oxygen atoms
Exercise

• Consider separate 100.0 g samples of each of the following:

\[ \text{H}_2\text{O}, \text{N}_2\text{O}, \text{C}_3\text{H}_6\text{O}_2, \text{CO}_2 \]

– Rank them in descending order of number of oxygen atoms

\[ \text{H}_2\text{O}, \text{CO}_2, \text{C}_3\text{H}_6\text{O}_2, \text{N}_2\text{O} \]
The formula of aspirin is $C_9H_8O_4$. Calculate the number of molecules in a 0.325 g tablet of aspirin.

a. $1.81 \times 10^{-3}$
b. $1.09 \times 10^{21}$
c. $6.02 \times 10^{23}$
d. $1.09 \times 10^{-23}$
The formula of aspirin is $\text{C}_9\text{H}_8\text{O}_4$. Calculate the number of molecules in a 0.325 g tablet of aspirin.

a. $1.81 \times 10^{-3}$  
b. $1.09 \times 10^{21}$  
c. $6.02 \times 10^{23}$  
d. $1.09 \times 10^{-23}$
Chemical Reactions - An Overview

- **Chemical equation**: A written statement that uses chemical symbols and chemical formulas to describe the changes that occur in a chemical reaction.

\[
\text{CaS} + \text{H}_2\text{O} \rightarrow \text{CaO} + \text{H}_2\text{S}
\]

- **Reactants** are always placed on the left side of the arrow.
- **Products** are always placed on the right side of the arrow.
Balanced chemical equation:

\[ \text{CaS} + \text{H}_2\text{O} \rightarrow \text{CaO} + \text{H}_2\text{S} \]

- Word description - 1 mole of calcium sulfide reacts with 1 mole of water to produce 1 mole of calcium oxide and 1 mole of hydrogen sulfide.
- All atoms present in the reactants are accounted for in the products.
Section 6.6
Writing and Balancing Chemical Equations

Equation Coefficient

• A number that is placed to the left of a chemical formula in a chemical equation
  – It changes the amount, but not the identity, of the substance

• The coefficients in the balanced equation do not affect the amount of each reactant given in a problem
  – Used to decide the amount of each reactant that is used, and the amount of each product that is formed in a reaction
Guidelines for Balancing Chemical Equations

1. Examine the equation and pick one element to balance first
2. Pick a second element to balance, and so on
3. As a final check, count atoms on each side of the equation
Writing and Balancing Chemical Equations

Points to Consider while Balancing Chemical Equations

• The number of atoms of each kind of element must be the same on both sides of a balanced equation
• Subscripts must not be changed to balance an equation
• Since only rearrangement occurs, products and reactants contain the same number of atoms of each kind
• Coefficients are always the smallest set of whole numbers that will balance the equation
Section 6.6
Writing and Balancing Chemical Equations

Exercise

• Which of the following correctly balances the chemical equation given below?

\[ \text{CaO} + \text{C} \rightarrow \text{CaC}_2 + \text{CO}_2 \]

I. \[ \text{CaO}_2 + 3\text{C} \rightarrow \text{CaC}_2 + \text{CO}_2 \]
II. \[ 2\text{CaO} + 5\text{C} \rightarrow 2\text{CaC}_2 + \text{CO}_2 \]
III. \[ \text{CaO} + (2.5)\text{C} \rightarrow \text{CaC}_2 + (0.5)\text{CO}_2 \]
IV. \[ 4\text{CaO} + 10\text{C} \rightarrow 2\text{CaC}_2 + 2\text{CO}_2 \]
Section 6.6
Writing and Balancing Chemical Equations

Exercise

Which of the following correctly balances the chemical equation given below?

\[ \text{CaO} + \text{C} \rightarrow \text{CaC}_2 + \text{CO}_2 \]

I. \[ \text{CaO}_2 + 3\text{C} \rightarrow \text{CaC}_2 + \text{CO}_2 \]
II. \[ 2\text{CaO} + 5\text{C} \rightarrow 2\text{CaC}_2 + \text{CO}_2 \]
III. \[ \text{CaO} + (2.5)\text{C} \rightarrow \text{CaC}_2 + (0.5)\text{CO}_2 \]
IV. \[ 4\text{CaO} + 10\text{C} \rightarrow 2\text{CaC}_2 + 2\text{CO}_2 \]
Concept Check

Which of the following are true concerning balanced chemical equations? There may be more than one true statement.

I. The number of molecules is conserved.
II. The coefficients tell you how much of each substance you have.
III. Atoms are neither created nor destroyed.
IV. The coefficients indicate the mass ratios of the substances used.
V. The sum of the coefficients on the reactant side equals the sum of the coefficients on the product side.
Concept Check

- Which of the following are true concerning balanced chemical equations? There may be more than one true statement.
  
  I. The number of molecules is conserved.
  
  II. The coefficients tell you how much of each substance you have.

  III. Atoms are neither created nor destroyed.

  IV. The coefficients indicate the mass ratios of the substances used.

  V. The sum of the coefficients on the reactant side equals the sum of the coefficients on the product side.
What is the correct balanced chemical equation for the process of heating sodium bicarbonate to produce sodium carbonate, carbon dioxide, and water?

a. $\text{NaHCO}_3 \rightarrow \text{NaCO}_3 + \text{CO}_2 + \text{H}_2 \text{O}$
b. $4\text{NaHCO}_3 \rightarrow 2\text{NaCO}_3 + 2\text{CO}_2 + 2\text{H}_2 \text{O}$
c. $2\text{NaHCO}_3 \rightarrow \text{Na}_2 \text{CO}_3 + \text{CO}_2 + \text{H}_2 \text{O}$
d. $4\text{NaHCO}_3 \rightarrow 2\text{Na}_2 \text{CO}_3 + 2\text{CO}_2 + 2\text{H}_2 \text{O}$
What is the correct balanced chemical equation for the process of heating sodium bicarbonate to produce sodium carbonate, carbon dioxide, and water?

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b. $4\text{NaHCO}_3 \rightarrow 2\text{NaCO}_3 + 2\text{CO}_2 + 2\text{H}_2\text{O}$
c. $2\text{NaHCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O}$
d. $4\text{NaHCO}_3 \rightarrow 2\text{Na}_2\text{CO}_3 + 2\text{CO}_2 + 2\text{H}_2\text{O}$
Coefficients in a Balanced Chemical Equation

\[ 4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3 \]

- Four molecules of Fe react with three molecules of \( \text{O}_2 \) to produce two molecules of \( \text{Fe}_2\text{O}_3 \)
  - Four moles of Fe react with three moles of \( \text{O}_2 \) to produce two moles of \( \text{Fe}_2\text{O}_3 \)
Use of Coefficients to Generate Conversion Factors

- 4 moles of Fe produce 2 moles of Fe$_2$O$_3$
- 3 moles of O$_2$ produce 2 moles of Fe$_2$O$_3$

\[
\frac{4 \text{ moles Fe}}{2 \text{ moles Fe}_2\text{O}_3} \text{ and } \frac{2 \text{ moles Fe}_2\text{O}_3}{4 \text{ moles Fe}}
\]
In the equation $\text{C}_2\text{H}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$, what are the correct coefficients in the balanced equation, and what is the correct mole-to-mole relationship?

a. $1, 3.5, 2, 3$ ; 1 mole of $\text{C}_2\text{H}_6$ produces 3 moles of $\text{H}_2\text{O}$

b. $4, 14, 8, 6$ ; 4 moles of $\text{C}_2\text{H}_6$ produce 6 moles of $\text{H}_2\text{O}$

c. $1, 2, 3, 3$ ; 1 mole of $\text{C}_2\text{H}_6$ produces 3 moles of $\text{H}_2\text{O}$

d. $2, 7, 4, 6,$ ; 2 moles of $\text{C}_2\text{H}_6$ produce 6 moles of $\text{H}_2\text{O}$
In the equation \( C_2H_6 + O_2 \rightarrow CO_2 + H_2O \), what are the correct coefficients in the balanced equation, and what is the correct mole-to-mole relationship?

a. 1, 3.5, 2, 3 ; 1 mole of \( C_2H_6 \) produces 3 moles of \( H_2O \)
b. 4, 14, 8, 6 ; 4 moles of \( C_2H_6 \) produce 6 moles of \( H_2O \)
c. 1, 2, 3, 3 ; 1 mole of \( C_2H_6 \) produces 3 moles of \( H_2O \)
d. 2, 7, 4, 6, ; 2 moles of \( C_2H_6 \) produce 6 moles of \( H_2O \)
Stoichiometric Calculations

• Chemical equations can be used to relate the masses of reacting chemicals
Figure 6.11 - Calculating Masses of Reactants and Products in Reactions
Exercise (Part I)

- Methane \((\text{CH}_4)\) reacts with the oxygen in the air to produce carbon dioxide and water

- Ammonia \((\text{NH}_3)\) reacts with the oxygen in the air to produce nitrogen monoxide and water

- Write balanced equations for each of these reactions
Exercise (Part I)

• Methane (CH$_4$) reacts with the oxygen in the air to produce carbon dioxide and water

$$\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$$

• Ammonia (NH$_3$) reacts with the oxygen in the air to produce nitrogen monoxide and water

$$4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O}$$

• 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?
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?

1.42 g
Yields: Theoretical, Actual, and Percent

• **Theoretical yield**: Maximum amount of a product that can be derived from given amounts of reactants on a reaction if no losses or inefficiencies of any kind occur.

• **Actual yield**: Amount of product actually obtained from a chemical reaction.

• **Percent yield**: Ratio of actual yield to theoretical yield multiplied by 100.
Yields: Theoretical, Actual, and Percent

What would be the percentage yield of a product for a chemical reaction where the theoretical yield and actual yield are, respectively, 5.6 g and 4.5 g?

a. 124.44%
b. 80%
c. 123.38%
d. No correct response
What would be the percentage yield of a product for a chemical reaction where the theoretical yield and actual yield are, respectively, 5.6 g and 4.5 g?

a. 124.44%

b. 80%

c. 123.38%

d. No correct response
Concept Question 1

- Pennies produced prior to 1982 were composed of 95% copper. On an average, these pennies weighed 3.11 g. How many atoms of copper were present in one pre-1982 penny? (Hint: Remember significant figures)

a. $1.87 \times 10^{24}$ atoms
b. $0.29 \times 10^{22}$ atoms
c. $2.8 \times 10^{22}$ atoms
d. $2.858 \times 10^{22}$ atoms
Concept Question 1

- Pennies produced prior to 1982 were composed of 95% copper. On an average, these pennies weighed 3.11 g. How many atoms of copper were present in one pre-1982 penny? (Hint: Remember significant figures)

a. $1.87 \times 10^{24}$ atoms
b. $0.29 \times 10^{22}$ atoms
c. $2.8 \times 10^{22}$ atoms
d. $2.858 \times 10^{22}$ atoms
Concept Question 2

- A 2 L bottle of carbonated soda has, on an average, 0.20 g of glucose per 100 mL. Glucose is metabolized in the human body according to the equation $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$. Which of the following equations would be used to determine the number of grams of CO$_2$ produced after the consumption of ten 2 L bottles of carbonated soda?

  a. $\frac{0.2 \text{ g}}{100 \text{ mL}} \times 20 \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times \frac{6 \text{ Moles CO}_2}{\text{Mole glucose}} \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} \times 10 = 59 \text{ g}$

  b. $\frac{0.2 \text{ g}}{100 \text{ mL}} \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times \frac{6 \text{ Moles CO}_2}{\text{Mole glucose}} \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} \times 10 = 2.9 \text{ g}$

  c. $\frac{0.2 \text{ g}}{100 \text{ mL}} \times 20 \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times \frac{6 \text{ Moles CO}_2}{\text{Mole glucose}} \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} = 5.9 \text{ g}$

  d. $\frac{0.2 \text{ g}}{100 \text{ mL}} \times 20 \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times \frac{\text{Moles CO}_2}{\text{Mole glucose}} \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} \times 10 = 9.8 \text{ g}$
Concept Question 2

A 2 L bottle of carbonated soda has, on an average, 0.20 g of glucose per 100 mL. Glucose is metabolized in the human body according to the equation \( \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \)

Which of the following equations would be used to determine the number of grams of \( \text{CO}_2 \) produced after the consumption of ten 2 L bottles of carbonated soda?

a. \[
\frac{0.2 \text{ g}}{100 \text{ mL}} \times 20 \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times \frac{6 \text{ Mole CO}_2}{\text{Mole glucose}} \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} \times 10 = 59 \text{ g}
\]

b. \[
\frac{0.2 \text{ g}}{100 \text{ mL}} \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times 6 \text{ Mole CO}_2 \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} \times 10 = 2.9 \text{ g}
\]

c. \[
\frac{0.2 \text{ g}}{100 \text{ mL}} \times 20 \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times 6 \text{ Mole CO}_2 \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} = 5.9 \text{ g}
\]

d. \[
\frac{0.2 \text{ g}}{100 \text{ mL}} \times 20 \times \frac{\text{Moles glucose}}{180 \text{ g glucose}} \times \frac{\text{Moles CO}_2}{\text{Mole glucose}} \times \frac{44 \text{ g CO}_2}{\text{Mole CO}_2} \times 10 = 9.8 \text{ g}
\]