Mass and Number. During any chemical reaction, such as this spectacular one between sodium and bromine to form sodium bromide, total mass is constant but individual masses change. As you'll see in this chapter, weighing provides a means for knowing not only the mass of each substance involved in a reaction but also the number of atoms, ions, or molecules undergoing the change.

Stoichiometry of Formulas and Equations

3.1 The Mole
Defining the Mole
Molar Mass
Mole-Mass-Number Conversions
Mass Percent

3.2 Determining the Formula of an Unknown Compound
Empirical Formulas
Molecular Formulas
Formulas and Structures

3.3 Writing and Balancing Chemical Equations

3.4 Calculating Amounts of Reactant and Product
Molar Ratios from Balanced Equations
Reaction Sequences
Limiting Reactants
Reaction Yields

3.5 Fundamentals of Solution Stoichiometry
Molarity
Solution Mole-Mass-Number Conversions
Preparation of Molar Solutions
Reactions in Solution
Figure 3.15 An overview of the key mass-mole-number stoichiometric relationships.

Chapter Review Guide

The following sections provide many aids to help you study this chapter. (Numbers in parentheses refer to pages, unless noted otherwise.)

Learning Objectives These are concepts and skills you should know after studying this chapter.

Relevant section and/or sample problem (SP) numbers appear in parentheses.

Understand These Concepts
1. The meaning and usefulness of the mole (3.1)
2. The relation between molecular (or formula) mass and molar mass (3.1)
3. The relations among amount of substance (in moles), mass (in grams), and number of chemical entities (3.1)
4. The information in a chemical formula (3.1)
5. The procedure for finding the empirical and molecular formulas of a compound (3.2)
6. How more than one substance can have the same empirical formula and the same molecular formula (isomers) (3.2)
7. The importance of balancing equations for the quantitative study of chemical reactions (3.3)
8. The mole-mass-number information in a balanced equation (3.3)
9. The relation between amounts of reactants and products (3.4)
10. Why one reactant limits the yield of product (3.4)
11. The causes of lower-than-expected yields and the distinction between theoretical and actual yields (3.4)
12. The meanings of concentration and molarity (3.5)
13. The effect of dilution on the concentration of solute (3.5)
14. How reactions in solution differ from those of pure reactants (3.5)

Master These Skills
1. Calculating the molar mass of any substance (3.1; also SPs 3.3, 3.4)
2. Converting between amount of substance (in moles), mass (in grams), and number of chemical entities (SPs 3.1–3.3)
3. Using mass percent to find the mass of element in a given mass of compound (SP 3.4)
4. Determining empirical and molecular formulas of a compound from mass percent and molar mass of elements (SPs 3.5, 3.6)
5. Determining a molecular formula from combustion analysis (SP 3.7)
6. Converting a chemical statement or a molecular depiction into a balanced equation (SP 3.8, 3.9)
7. Using stoichiometrically equivalent molar ratios to calculate amounts of reactants and products in reactions of pure and dissolved substances (SPs 3.10, 3.19)
8. Writing an overall equation from a series of equations (SP 3.11)
9. Solving limiting-reactant problems from molecular depictions and for reactions of pure and dissolved substances (SPs 3.12, 3.13, 3.20)
10. Calculating percent yield (SP 3.14)
11. Calculating molarity and the mass of solute in solution (SPs 3.15, 3.16)
12. Preparing a dilute solution from a concentrated one (SP 3.17)
13. Using molecular depictions to understand changes in volume (SP 3.18)
Key Terms These important terms appear in boldface in the chapter and are defined again in the Glossary.

- stoichiometry (90)
- mole (mol) (90)
- Avogadro’s number (90)
- molar mass (M) (92)
- combustible analysis (101)
- isomer (103)
- chemical equation (104)
- reactant (105)
- product (105)
- balancing (stoichiometric) coefficient (105)
- percent yield (% yield) (118)
- green chemistry (120)
- solute (121)
- solvent (121)
- concentration (121)
- molarity (M) (121)

Key Equations and Relationships Numbered and screened concepts are listed for you to refer to or memorize.

3.1 Number of entities in one mole (90): 1 mol contains $6.022 \times 10^{23}$ entities (to 4 sf)

3.2 Converting amount (mol) to mass using $\text{M}$ (93):

$$\text{Mass (g)} = \text{no. of moles} \times \frac{1\text{ mol}}{6.022 \times 10^{23}\text{ entities}}$$

3.3 Converting mass to amount (mol) using $1/\text{M}$ (93):

$$\text{No. of moles} = \frac{\text{mass (g)}}{\text{no. of grams}}$$

3.4 Converting amount (mol) to number of entities (93):

$$\text{No. of entities} = \text{no. of moles} \times 6.022 \times 10^{23}\text{ entities}$$

3.5 Converting number of entities to amount (mol) (93):

$$\text{No. of moles} = \frac{\text{no. of entities}}{6.022 \times 10^{23}\text{ entities}}$$

3.6 Calculating mass % (96):

$$\text{Mass % of element X} = \frac{\text{mass (g) of X in formula}}{\text{mass (g) of 1 mol of compound}} \times 100$$

3.7 Calculating percent yield (118):

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

3.8 Defining molarity (121):

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{liters of solution}} \text{ or } M = \frac{\text{mol solute}}{\text{L soln}}$$

3.9 Diluting a concentrated solution (124):

$$M_{\text{dil}} \times V_{\text{dil}} = \text{number of moles} = M_{\text{conc}} \times V_{\text{conc}}$$

Highlighted Figures and Tables These figures (F) and tables (T) provide a visual review of key ideas.

- T3.1 Summary of mass terminology (92)
- T3.2 Information contained in a formula (93)
- T3.3 Mass-mole-number relationships for elements (94)
- T3.4 Mass-mole-number relationships for compounds (95)
- F3.5 Information contained in a balanced equation (110)
- T3.5 Information contained in a balanced equation (110)
- F3.9 Mass-mole-number relationships in a chemical reaction (111)
- F3.12 Mass-mole-number-volume relationships in solution (122)
- F3.15 Overview of mass-mole-number relationships (128)

Brief Solutions to FOLLOW-UP PROBLEMS Compare your solutions to these calculation steps and answers.

3.1 Moles of C = $315 \text{ mg C} \times \frac{1\text{ g C}}{10^{-3}\text{ mg C}} \times \frac{1\text{ mol C}}{12.01\text{ g C}}$

= $2.62 \times 10^{-2}\text{ mol C}$

3.2 Mass (g) of Mn = $3.22 \times 10^{20} \text{ Mn atoms} \times \frac{1\text{ mol Mn}}{6.022 \times 10^{23}\text{ Mn atoms}} \times \frac{54.94\text{ g Mn}}{1\text{ mol Mn}}$

= $2.94 \times 10^{-2}\text{ g Mn}$

3.3 (a) Mass (g) of $\text{P}_4\text{O}_{10}$

= $4.65 \times 10^{22} \text{ molecules P}_4\text{O}_{10} \times \frac{283.88\text{ g P}_4\text{O}_{10}}{1\text{ mol P}_4\text{O}_{10}} \times \frac{6.022 \times 10^{23}\text{ molecules P}_4\text{O}_{10}}{1\text{ mol P}_4\text{O}_{10}}$

= $21.9\text{ g P}_4\text{O}_{10}$

(b) No. of P atoms = $4.65 \times 10^{22} \text{ molecules P}_4\text{O}_{10} \times \frac{4\text{ atoms P}}{1\text{ molecule P}_4\text{O}_{10}}$

= $1.86 \times 10^{23}\text{ P atoms}$

3.4 (a) Mass % of N = $\frac{2\text{ mol N} \times 14.01\text{ g N}}{1\text{ mol N}} \times \frac{80.05\text{ g NH}_4\text{NO}_3}{35.00\text{ mass %}}$

= $35.00\text{ mass % N}$

(b) Mass (g) of N = $35.8\text{ kg NH}_4\text{NO}_3 \times \frac{10^{3}\text{ g}}{1\text{ kg}} \times \frac{0.3500\text{ g N}}{1\text{ g NH}_4\text{NO}_3}$

= $1.25 \times 10^{4}\text{ g N}$

3.5 Moles of S = $2.88 \times \frac{1\text{ mol S}}{32.07\text{ g S}}$

= $0.0898\text{ mol S}$

Moles of M = $0.0898\text{ mol S} \times \frac{2\text{ mol M}}{3\text{ mol S}}$

= $0.0599\text{ mol M}$

Molar mass of M = $\frac{3.12\text{ g M}}{0.0599\text{ mol M}}$

= 52.1 g/mol

M is chromium, and $\text{M}_2\text{S}_3$ is chromium(III) sulfide.