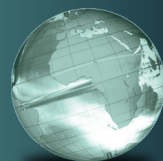


GLOBAL  
EDITION



# Chemistry

## *The Central Science*

Expanded Edition

Fifteenth Global Edition in SI Units

Brown • LeMay • Bursten  
Murphy • Woodward • Stoltzfus  
Langford • George





# Periodic Table of the Elements

Main Group  
Representative Elements

1A<sup>a</sup>  
1

1  
**H**  
1.00794

2A  
2

2  
**He**  
4.002602

3A  
13

3  
**B**  
10.811

4A  
14

4  
**C**  
12.0107

5A  
15

5  
**N**  
14.0067

6A  
16

6  
**O**  
15.9994

7A  
17

7  
**F**  
18.998403

8A  
18

8  
**Ne**  
20.1797

Metals

Metalloids

Nonmetals

Transition metals

8B

9

10

11

12

1B

2B

3  
**Na**  
22.989770

4  
**K**  
39.0983

5  
**Rb**  
85.4678

6  
**Cs**  
132.90545

7  
**Fr**  
[223.02]

8  
**Mg**  
24.3050

9  
**Ca**  
40.078

10  
**Sr**  
87.62

11  
**Ba**  
137.327

12  
**Ra**  
[226.03]

13  
**Al**  
26.981538

14  
**Si**  
28.0855

15  
**P**  
30.973761

16  
**S**  
32.065

17  
**Cl**  
35.453

18  
**Ar**  
39.948

19  
**Sc**  
44.955910

20  
**Ti**  
47.867

21  
**V**  
50.9415

22  
**Cr**  
51.9961

23  
**Mn**  
54.938049

24  
**Fe**  
55.845

25  
**Co**  
58.933200

26  
**Ni**  
58.6934

27  
**Cu**  
63.546

28  
**Zn**  
65.39

29  
**Ga**  
69.723

30  
**Ge**  
72.64

31  
**As**  
74.92160

32  
**Se**  
78.96

33  
**Br**  
79.904

34  
**Kr**  
83.80

35  
**Y**  
88.90585

36  
**Zr**  
91.224

37  
**Nb**  
92.90638

38  
**Mo**  
95.94

39  
**Tc**  
[98]

40  
**Ru**  
101.07

41  
**Rh**  
102.90550

42  
**Pd**  
106.42

43  
**Ag**  
107.8682

44  
**Cd**  
112.411

45  
**In**  
114.818

46  
**Sn**  
118.710

47  
**Sb**  
121.760

48  
**Te**  
127.60

49  
**I**  
126.90447

50  
**Xe**  
131.293

51  
**Lu**  
174.967

52  
**Hf**  
178.49

53  
**Ta**  
180.9479

54  
**W**  
183.84

55  
**Re**  
186.207

56  
**Os**  
190.23

57  
**Ir**  
192.217

58  
**Pt**  
195.078

59  
**Au**  
196.96655

60  
**Hg**  
200.59

61  
**Pm**  
[145]

62  
**Sm**  
150.36

63  
**Eu**  
151.964

64  
**Gd**  
157.25

65  
**Tb**  
158.92534

66  
**Dy**  
162.50

67  
**Ho**  
164.93032

68  
**Er**  
167.259

69  
**Tm**  
168.93421

70  
**Yb**  
173.04

71  
**La**  
138.9055

72  
**Ce**  
140.116

73  
**Pr**  
140.90765

74  
**Nd**  
144.24

75  
**Pm**  
[237.05]

76  
**Sm**  
150.36

77  
**Eu**  
151.964

78  
**Gd**  
157.25

79  
**Tb**  
158.92534

80  
**Dy**  
162.50

81  
**Ho**  
164.93032

82  
**Er**  
167.259

83  
**Tm**  
168.93421

84  
**Yb**  
173.04

85  
**Ac**  
[227.03]

86  
**Th**  
232.0381

87  
**Pa**  
231.03588

88  
**U**  
238.02891

89  
**Np**  
[237.05]

90  
**Pu**  
[244.06]

91  
**Am**  
[243.06]

92  
**Cm**  
[247.07]

93  
**Bk**  
[247.07]

94  
**Cf**  
[251.08]

95  
**Es**  
[252.08]

96  
**Fm**  
[257.10]

97  
**No**  
[259.10]

<sup>a</sup>The labels on top (1A, 2A, etc.) are common American usage. The labels below these (1, 2, etc.) are those recommended by the International Union of Pure and Applied Chemistry (IUPAC).

Except for elements 114 and 116, the names and symbols for elements above 113 have not yet been decided.

Atomic weights in brackets are the names of the longest-lived or most important isotope of radioactive elements.

Further information is available at <http://www.webelements.com>

\*\* Discovered in 2010, element 117 is currently under review by IUPAC.

# Chemistry: The Central Science in SI Units, Expanded Edition, Global Edition

## Table of Contents

Cover

Periodic Table of the Elements

List of Elements with Their Symbols and Atomic Weights

Half Title

Title Page

Copyright

Dedication

Brief Contents

Contents

Chemical Applications and Essays

Interactive Media

Preface

About the Authors

Visual Walkthrough

New Levels of Student Interaction for Improved Conceptual Understanding

Visually Revised to Better Help Students Build Chemistry

Knowledge and Understanding

Continuous Learning Before, During, and After Class with Pearson Mastering Chemistry (I)

Continuous Learning Before, During, and After Class with Pearson Mastering Chemistry  
(II)

Continuous Learning Before, During, and After Class with Pearson Mastering Chemistry  
(III)

Continuous Learning Before, During, and After Class with Pearson Mastering Chemistry  
(IV)

Instructor and Student Resources

Chapter 1: Introduction: Matter, Energy, and Measurement

1.1 The Study of Chemistry

# **Table of Contents**

The Atomic and Molecular Perspective of Chemistry

Why Study Chemistry?

## **1.2 Classifications of Matter**

States of Matter

Pure Substances

Elements

Compounds

Mixtures

## **1.3 Properties of Matter**

Physical and Chemical Changes

Separation of Mixtures

## **1.4 The Nature of Energy**

Kinetic Energy and Potential Energy

## **1.5 Units of Measurement**

SI Units

Length and Mass

Temperature

Derived SI Units

Volume

Density

Units of Energy

## **1.6 Uncertainty in Measurement**

Precision and Accuracy

Significant Figures

Significant Figures in Calculations

## **1.7 Dimensional Analysis**

Conversion Factors

Using Two or More Conversion Factors

Conversions Involving Volume

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Chemistry Put to Work Chemistry and the Chemical Industry

A Closer Look The Scientific Method

# **Table of Contents**

Chemistry Put to Work Chemistry in the News  
Strategies for Success Estimating Answers  
Strategies for Success The Importance of Practice  
Strategies for Success The Features of This Book

## **Chapter 2: Atoms, Molecules, and Ions**

### **2.1 The Atomic Theory of Matter**

### **2.2 The Discovery of Atomic Structure**

Cathode Rays and Electrons

Radioactivity

The Nuclear Model of the Atom

### **2.3 The Modern View of Atomic Structure**

Atomic Numbers, Mass Numbers, and Isotopes

### **2.4 Atomic Weights**

The Atomic Mass Scale

Atomic Weight

### **2.5 The Periodic Table**

### **2.6 Molecules and Molecular Compounds**

Molecules and Chemical Formulas

Molecular and Empirical Formulas

Picturing Molecules

### **2.7 Ions and Ionic Compounds**

Predicting Ionic Charges

Ionic Compounds

### **2.8 Naming Inorganic Compounds**

Names and Formulas of Ionic Compounds

Names and Formulas of Acids

Names and Formulas of Binary Molecular Compounds

### **2.9 Some Simple Organic Compounds**

Alkanes

Some Derivatives of Alkanes

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

# **Table of Contents**

A Closer Look Basic Forces

A Closer Look The Mass Spectrometer

Chemistry and Life Elements Required by Living Organisms

Strategies for Success How to Take a Test

## **Chapter 3: Chemical Reactions and Stoichiometry**

### **3.1 The Conservation of Mass, Chemical Equations, and Stoichiometry**

How to Balance Chemical Equations

A Step-by-Step Example of Balancing a Chemical Equation

### **3.2 Simple Patterns of Chemical Reactivity: Combination, Decomposition, and Combustion**

Combination and Decomposition Reactions

Combustion Reactions

### **3.3 Formula Weights and Elemental Compositions of Substances**

Formula and Molecular Weights

Elemental Compositions of Substances

### **3.4 Avogadro's Number and the Mole; Molar Mass**

The Mole and Avogadro's Number

Molar Mass

Converting Between Masses, Moles, and Atoms/Molecules/Ions

### **3.5 Formula Weights and Elemental Compositions of Substances**

Molecular Formulas from Empirical Formulas

Combustion Analysis

### **3.6 Reaction Stoichiometry**

### **3.7 Limiting Reactants**

Theoretical and Percent Yields

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Strategies for Success Problem Solving

Chemistry and Life Glucose Monitoring

# **Table of Contents**

Strategies for Success Design an Experiment

## **Chapter 4: Reactions in Aqueous Solution**

### **4.1 General Properties of Aqueous Solutions**

Electrolytes and Nonelectrolytes

How Compounds Dissolve in Water

Strong and Weak Electrolytes

### **4.2 Precipitation Reactions**

Solubility Guidelines for Ionic Compounds

Exchange (Metathesis) Reactions

Ionic Equations and Spectator Ions

### **4.3 Acids, Bases, and Neutralization Reactions**

Acids

Bases

Strong and Weak Acids and Bases

Identifying Strong and Weak Electrolytes

Neutralization Reactions and Salts

Neutralization Reactions with Gas Formation

### **4.4 OxidationReduction Reactions**

Oxidation and Reduction

Oxidation Numbers

Oxidation of Metals by Acids and Salts

The Activity Series

### **4.5 Concentrations of Solutions**

Molarity

Expressing the Concentration of an Electrolyte

Interconverting Molarity, Moles, and Volume

Dilution

### **4.6 Solution Stoichiometry and Chemical Analysis**

Titration

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

# **Table of Contents**

Design an Experiment

Chemistry Put to Work Antacids

Strategies for Success Analyzing Chemical Reactions

## **Chapter 5: Thermochemistry**

5.1 The Nature of Chemical Energy

5.2 The First Law of Thermodynamics

System and Surroundings

Internal Energy

Relating E to Heat and Work

Endothermic and Exothermic Processes

State Functions

5.3 Enthalpy

PressureVolume Work

Enthalpy Change

5.4 Enthalpies of Reaction

5.5 Calorimetry

Heat Capacity and Specific Heat

Constant-Pressure Calorimetry

Bomb Calorimetry (Constant-Volume Calorimetry)

5.6 Hess's Law

5.7 Enthalpies of Formation

Using Enthalpies of Formation to Calculate Enthalpies of Reaction

5.8 Bond Enthalpies

Bond Enthalpies and the Enthalpies of Reactions

5.9 Foods and Fuels

Foods

Fuels

Other Energy Sources

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment



# **Table of Contents**

A Closer Look Energy, Enthalpy, and P-V Work

A Closer Look Using Enthalpy as a Guide

Chemistry and Life The Regulation of Body Temperature

Chemistry Put to Work The Scientific and Political Challenges of Biofuels

## **Chapter 6: Electronic Structure of Atoms**

6.1 The Wave Nature of Light

6.2 Quantized Energy and Photons

Hot Objects and the Quantization of Energy

The Photoelectric Effect and Photons

6.3 Line Spectra and the Bohr Model

Line Spectra

Bohrs Model

The Energy States of the Hydrogen Atom

Limitations of the Bohr Model

6.4 The Wave Behavior of Matter

The Uncertainty Principle

6.5 Quantum Mechanics and Atomic Orbitals

Orbitals and Quantum Numbers

6.6 Representations of Orbitals

The s Orbitals

The p Orbitals

The d and f Orbitals

6.7 Many-Electron Atoms

Orbitals and Their Energies

Electron Spin and the Pauli Exclusion Principle

6.8 Electron Configurations

Hunds Rule

Condensed Electron Configurations

Transition Metals

The Lanthanides and Actinides

6.9 Electron Configurations and the Periodic Table

Anomalous Electron Configurations

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

# **Table of Contents**

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Measurement and the Uncertainty Principle

A Closer Look Thought Experiments and Schrödingers Cat

A Closer Look Probability Density and Radial Probability Functions

Chemistry and Life Nuclear Spin and Magnetic Resonance Imaging

## **Chapter 7: Periodic Properties of the Elements**

7.1 Development of the Periodic Table

7.2 Effective Nuclear Charge

7.3 Sizes of Atoms and Ions

Periodic Trends in Atomic Radii

Periodic Trends in Ionic Radii

7.4 Ionization Energy

Variations in Successive Ionization Energies

Periodic Trends in First Ionization Energies

Electron Configurations of Ions

7.5 Electron Affinity

Periodic Trends in Electron Affinity

7.6 Metals, Nonmetals, and Metalloids

Metals

Nonmetals

Metalloids

7.7 Trends for Group 1 and Group 2 Metals

Group 1: The Alkali Metals

Group 2: The Alkaline Earth Metals

7.8 Trends for Selected Nonmetals

Hydrogen

Group 16: The Oxygen Group

Group 17: The Halogens

Group 18: The Noble Gases

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

# Table of Contents

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Effective Nuclear Charge

Chemistry Put to Work Ionic Size and Lithium-Ion Batteries

Chemistry and Life The Improbable Development of Lithium Drugs

## Chapter 8: Basic Concepts of Chemical Bonding

### 8.1 Lewis Symbols and the Octet Rule

Lewis Symbols

The Octet Rule

### 8.2 Ionic Bonding

Energetics of Ionic Bond Formation

Electron Configurations of Ions of the s- and p-Block Elements

Transition Metal Ions

### 8.3 Covalent Bonding

Lewis Structures

Multiple Bonds

### 8.4 Bond Polarity and Electronegativity

Electronegativity

Electronegativity and Bond Polarity

Dipole Moments

Comparing Ionic and Covalent Bonding

### 8.5 Drawing Lewis Structures

Formal Charge and Alternative Lewis Structures

### 8.6 Resonance Structures

Resonance in Benzene

### 8.7 Exceptions to the Octet Rule

Odd Number of Electrons

Less Than an Octet of Valence Electrons

More Than an Octet of Valence Electrons

### 8.8 Strengths and Lengths of Covalent Bonds

Chapter Summary and Key Terms

Learning Outcomes

Key Equations



# **Table of Contents**

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Calculation of Lattice Energies: The BornHaber Cycle

A Closer Look Oxidation Numbers, Formal Charges, and Actual Partial Charges

## **Chapter 9: Molecular Geometry and Bonding Theories**

9.1 Molecular Shapes

9.2 The VSEPR Model

Applying the VSEPR Model to Determine Molecular Shapes

Effect of Nonbonding Electrons and Multiple Bonds on Bond Angles

Molecules with Expanded Valence Shells

Shapes of Larger Molecules

9.3 Molecular Shape and Molecular Polarity

9.4 Covalent Bonding and Orbital Overlap

9.5 Hybrid Orbitals

sp Hybrid Orbitals

sp<sup>2</sup> and sp<sup>3</sup> Hybrid Orbitals

Hypervalent Molecules

Hybrid Orbital Summary

9.6 Multiple Bonds

Resonance Structures, Delocalization, and Bonding

General Conclusions about Bonding

9.7 Molecular Orbitals

Molecular Orbitals of the Hydrogen Molecule

Bond Order

9.8 Bonding in Period 2 Diatomic Molecules

Molecular Orbitals for Li<sub>2</sub> and Be<sub>2</sub>

Molecular Orbitals from 2p Atomic Orbitals

Electron Configurations for B<sub>2</sub> through Ne<sub>2</sub>

Electron Configurations and Molecular Properties

Heteronuclear Diatomic Molecules

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

# **Table of Contents**

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Phases in Atomic and Molecular Orbitals

Chemistry Put to Work Orbitals and Energy

## **Chapter 10: Gases**

10.1 Characteristics of Gases

10.2 Pressure

Atmospheric Pressure and the Barometer

10.3 The Gas Laws

The PressureVolume Relationship: Boyles Law

The TemperatureVolume Relationship: Charless Law

The QuantityVolume Relationship: Avogadros Law

10.4 The Ideal Gas Equation

Relating the Ideal Gas Equation and the Gas Laws

Gas Densities and Molar Mass

Volumes of Gases in Chemical Reactions

10.5 Gas Mixtures and Partial Pressures

Partial Pressures and Mole Fractions

10.6 The Kinetic-Molecular Theory of Gases

Distributions of Molecular Speed

Application of Kinetic-Molecular Theory to the Gas Laws

10.7 Molecular Effusion and Diffusion

Grahams Law of Effusion

Diffusion and Mean Free Path

10.8 Real Gases: Deviations from Ideal Behavior

The van der Waals Equation

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

# **Table of Contents**

Design an Experiment

Chemistry and Life Blood Pressure

Strategies for Success Calculations Involving Many Variables

A Closer Look The Ideal Gas Equation

Chemistry Put to Work Gas Separations

## **Chapter 11: Liquids and Intermolecular Forces**

11.1 A Molecular Comparison of Gases, Liquids, and Solids

11.2 Intermolecular Forces

Dispersion Forces

DipoleDipole Interactions

Hydrogen Bonding

IonDipole Forces

Comparing Intermolecular Forces

11.3 Select Properties of Liquids

Viscosity

Surface Tension

Capillary Action

11.4 Phase Changes

Energy Changes Accompany Phase Changes

Heating Curves

Critical Temperature and Pressure

11.5 Vapor Pressure

Volatility, Vapor Pressure, and Temperature

Vapor Pressure and Boiling Point

11.6 Phase Diagrams

The Phase Diagrams of H<sub>2</sub>O and CO<sub>2</sub>

11.7 Liquid Crystals

Types of Liquid Crystals

Chapter Summary and Key Terms

Learning Outcomes

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Chemistry Put to Work Ionic Liquids



# **Table of Contents**

A Closer Look The ClausiusClapeyron Equation

Chemistry and Life Liquid Crystal Displays

## **Chapter 12: Solids and Modern Materials**

### **12.1 Classification of Solids**

Crystalline and Amorphous Solids

Unit Cells and Crystal Lattices

Filling the Unit Cell

### **12.2 Metallic Solids**

The Structures of Metallic Solids

Close Packing

Alloys

Metallic Bonding

Electron-Sea Model

Molecular Orbital Model

### **12.3 Ionic Solids**

Structures of Ionic Solids

### **12.4 Covalent Solids**

Molecular Solids

Covalent-Network Solids

Semiconductors

Semiconductor Doping

### **12.5 Polymers**

Making Polymers

Structure and Physical Properties of Polymers

### **12.6 Nanomaterials**

Semiconductors on the Nanoscale

Metals on the Nanoscale

Carbon on the Nanoscale

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

# **Table of Contents**

A Closer Look X-ray Diffraction

Chemistry Put to Work Alloys of Gold

Chemistry Put to Work Solid-State Lighting

Chemistry Put to Work Modern Materials in the Automobile

Chemistry Put to Work Microporous and Mesoporous Materials

## **Chapter 13: Properties of Solutions**

### **13.1 The Solution Process**

The Natural Tendency toward Mixing

The Effect of Intermolecular Forces on Solution Formation

Energetics of Solution Formation

Solution Formation and Chemical Reactions

### **13.2 Saturated Solutions and Solubility**

### **13.3 Factors Affecting Solubility**

SoluteSolvent Interactions

Pressure Effects

Temperature Effects

### **13.4 Expressing Solution Concentration**

Mass Percentage, ppm, and ppb

Mole Fraction, Molarity, and Molality

Converting Concentration Units

### **13.5 Colligative Properties**

VaporPressure Lowering

Boiling-Point Elevation

Freezing-Point Depression

Osmosis

Determination of Molar Mass from Colligative Properties

### **13.6 Colloids**

Hydrophilic and Hydrophobic Colloids

Colloidal Motion in Liquids

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

# **Table of Contents**

Design an Experiment

Chemistry and Life Fat-Soluble and Water-Soluble Vitamins

Chemistry and Life Blood Gases and Deep-Sea Diving

A Closer Look Ideal Solutions with Two or More Volatile Components

A Closer Look The vant Hoff Factor

Chemistry and Life Sickle-Cell Anemia

## **Chapter 14: Chemical Kinetics**

### **14.1 Factors That Affect Reaction Rates**

### **14.2 Reaction Rates**

Change of Rate with Time

Instantaneous Rate

Reaction Rates and Stoichiometry

### **14.3 Concentration and Rate Laws**

Reaction Orders: The Exponents in the Rate Law

Magnitudes and Units of Rate Constants

Using Initial Rates to Determine Rate Laws

### **14.4 The Change of Concentration with Time**

First-Order Reactions

Second-Order Reactions

Zero-Order Reactions

Half-Life

### **14.5 Temperature and Rate**

The Collision Model

The Orientation Factor

Activation Energy

The Arrhenius Equation

Determining the Activation Energy

### **14.6 Reaction Mechanisms**

Elementary Reactions

Multistep Mechanisms

Rate Laws for Elementary Reactions

The Rate-Determining Step for a Multistep Mechanism

Mechanisms with a Slow Initial Step

Mechanisms with a Fast Initial Step

### **14.7 Catalysis**



# **Table of Contents**

Homogeneous Catalysis

Heterogeneous Catalysis

Enzymes

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Using Spectroscopic Methods to Measure Reaction Rates: Beers Law

Chemistry Put to Work Bromomethane in the Atmosphere

Chemistry Put to Work Catalytic Converters

Chemistry and Life Nitrogen Fixation and Nitrogenase

## **Chapter 15: Chemical Equilibrium**

15.1 The Concept of Equilibrium

15.2 The Equilibrium Constant

Evaluating  $K_c$

Equilibrium Constants in Terms of Pressure,  $K_p$

Equilibrium Constants and Units

15.3 Understanding and Working with Equilibrium Constants

The Magnitude of Equilibrium Constants

The Direction of the Chemical Equation and  $K$

Relating Chemical Equation Stoichiometry and Equilibrium Constants

Heterogeneous Equilibria

15.4 Calculating Equilibrium Constants

Applications of Equilibrium Constants

Predicting the Direction of Reaction

Calculating Equilibrium Concentrations

15.5 Le Châteliers Principle

Change in Reactant or Product Concentration

Effects of Volume and Pressure Changes

Effect of Temperature Changes

The Effect of Catalysts

# **Table of Contents**

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Chemistry Put to Work The Haber Process

A Closer Look Temperature Changes and Le Châteliers Principle

Chemistry Put to Work Controlling Nitric Oxide Emissions

## **Chapter 16: AcidBase Equilibria**

### **16.1 AcidBase Equilibria**

Arrhenius Acids and Bases

BrønstedLowry Acids and Bases

The  $H^+$  Ion in Water

Proton-Transfer Reactions

Conjugate AcidBase Pairs

Relative Strengths of Acids and Bases

### **16.2 The Autoionization of Water**

The Ion Product of Water

### **16.3 The pH Scale**

pOH and Other "p" Scales

Measuring pH

### **16.4 Strong Acids and Bases**

Strong Acids

Strong Bases

### **16.5 Weak Acids**

Calculating  $K_a$  from pH

Percent Ionization

Using  $K_a$  to Calculate pH

Polyprotic Acids

### **16.6 Weak Bases**

Types of Weak Bases

Relationship Between  $K_a$  and  $K_b$

### **16.7 AcidBase Properties of Salt Solutions**

# **Table of Contents**

An Anions Ability to React with Water

A Cations Ability to React with Water

Combined Effect of Cation and Anion in Solution

## **16.8 AcidBase Behavior and Chemical Structure**

Factors That Affect Acid Strength

Binary Acids

Oxyacids

Carboxylic Acids

Lewis Acids and Bases

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Polyprotic Acids

Chemistry Put to Work Amines and Amine Hydrochlorides

Chemistry and Life The Amphiprotic Behavior of Amino Acids

## **Chapter 17: Additional Aspects of Aqueous Equilibria**

### **17.1 The Common-Ion Effect**

### **17.2 Buffers**

Composition and Action of Buffers

Calculating the pH of a Buffer

Buffer Capacity and pH Range

Addition of Strong Acids or Bases to Buffers

### **17.3 AcidBase Titrations**

Strong AcidStrong Base Titrations

Weak AcidStrong Base Titrations

Titration with an AcidBase Indicator

Titrations of Polyprotic Acids

### **17.4 Solubility Equilibria**

The Solubility-Product Constant,  $K_{sp}$

Solubility and  $K_{sp}$

### **17.5 Factors That Affect Solubility**



# **Table of Contents**

The Common-Ion Effect

Solubility and pH

Formation of Complex Ions

Amphoterism

## **17.6 Precipitation and Separation of Ions**

Selective Precipitation of Ions

Qualitative Analysis for Metallic Elements

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Blood as a Buffered Solution

A Closer Look Limitations of Solubility Products

Chemistry and Life Tooth Decay and Fluoridation

A Closer Look Lead Contamination in Drinking Water

## **Chapter 18: Chemistry of the Environment**

### **18.1 Earths Atmosphere**

Composition of the Atmosphere

Photochemical Reactions in the Atmosphere

Ozone in the Stratosphere

### **18.2 Human Activities and Earths Atmosphere**

The Ozone Layer and Its Depletion

Sulfur Compounds and Acid Rain

Nitrogen Oxides and Photochemical Smog

Greenhouse Gases: Water Vapor, Carbon Dioxide, and Climate

### **18.3 Earths Water**

The Global Water Cycle

Salt Water: Earths Oceans and Seas

Freshwater and Groundwater

### **18.4 Human Activities and Water Quality**

Dissolved Oxygen and Water Quality

Water Purification: Desalination

# **Table of Contents**

Water Purification: Municipal Treatment

## **18.5 Green Chemistry**

Supercritical Solvents

Greener Reagents and Processes

Chapter Summary and Key Terms

Learning Outcomes

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Other Greenhouse Gases

A Closer Look Fracking and Water Quality

Chemistry and Life Ocean Acidification

## **Chapter 19: Chemical Thermodynamics**

### **19.1 Spontaneous Processes**

Seeking a Criterion for Spontaneity

Reversible and Irreversible Processes

### **19.2 Entropy and the Second Law of Thermodynamics**

The Relationship between Entropy and Heat

S for Phase Changes

The Second Law of Thermodynamics

### **19.3 The Molecular Interpretation of Entropy and the Third Law of Thermodynamics**

Expansion of a Gas at the Molecular Level

Boltzmanns Equation and Microstates

Molecular Motions and Energy

Making Qualitative Predictions about S

The Third Law of Thermodynamics

### **19.4 Entropy Changes in Chemical Reactions**

Temperature Variation of Entropy

Standard Molar Entropies

Calculating the Standard Entropy Change for a Reaction

Entropy Changes in the Surroundings

### **19.5 Gibbs Free Energy**

Standard Free Energy of Formation

# Table of Contents

19.6 Free Energy and Temperature

19.7 Free Energy and the Equilibrium Constant

Free Energy under Nonstandard Conditions

Relationship between  $G^\circ$  and  $K$

Chapter Summary and Key Terms

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look The Entropy Change When a Gas Expands Isothermally

Chemistry and Life Entropy and Human Society

A Closer Look Whats "Free" About Free Energy?

Chemistry and Life Driving Nonspontaneous Reactions: Coupling Reactions

## Chapter 20: Electrochemistry

20.1 Oxidation States and OxidationReduction Reactions

20.2 Balancing Redox Equations

Half-Reactions

Balancing Equations by the Method of Half-Reactions

Balancing Equations for Reactions Occurring in Basic Solution

20.3 Voltaic Cells

20.4 Cell Potentials under Standard Conditions

Standard Reduction Potentials

Strengths of Oxidizing and Reducing Agents

20.5 Free Energy and Redox Reactions

Emf, Free Energy, and the Equilibrium Constant

20.6 Cell Potentials under Nonstandard Conditions

The Nernst Equation

Concentration Cells

20.7 Batteries and Fuel Cells

LeadAcid Battery

Alkaline Battery

NickelCadmium and NickelMetal Hydride Batteries

# **Table of Contents**

Lithium-Ion Batteries

Hydrogen Fuel Cells

## **20.8 Corrosion**

Corrosion of Iron (Rusting)

Preventing Corrosion of Iron

## **20.9 Electrolysis**

Quantitative Aspects of Electrolysis

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look Electrical Work

Chemistry and Life Heartbeats and Electrocardiography

Chemistry Put to Work Batteries for Hybrid and Electric Vehicles

Chemistry Put to Work Electrometallurgy of Aluminum

## **Chapter 21: Nuclear Chemistry**

### **21.1 Radioactivity and Nuclear Equations**

Nuclear Equations

Types of Radioactive Decay

### **21.2 Patterns of Nuclear Stability**

Neutron-to-Proton Ratio

Radioactive Decay Chains

Further Observations

Nuclear Transmutations

Accelerating Charged Particles

Reactions Involving Neutrons

Transuranium Elements

### **21.3 Rates of Radioactive Decay**

Radiometric Dating

Calculations Based on Half-Life

### **21.4 Detection of Radioactivity**

Radiotracers

# **Table of Contents**

## **21.5 Energy Changes in Nuclear Reactions**

Nuclear Binding Energies

Nuclear Power: Fission

Nuclear Reactors

Nuclear Waste

Nuclear Power: Fusion

## **21.6 Radiation in the Environment and Living Systems**

Radiation Doses

## **Chapter Summary and Key Terms**

Learning Outcomes

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Medical Applications of Radiotracers

A Closer Look The Dawning of the Nuclear Age

A Closer Look Nuclear Synthesis of the Elements

Chemistry and Life Radiation Therapy

## **Chapter 22: Chemistry of the Nonmetals**

### **22.1 Periodic Trends and Chemical Reactions**

Chemical Reactions

### **22.2 Hydrogen**

Isotopes of Hydrogen

Properties of Hydrogen

Production of Hydrogen

Uses of Hydrogen

Binary Hydrogen Compounds

### **22.3 Group 18: The Noble Gases**

Noble Gas Compounds

### **22.4 Group 17: The Halogens**

Properties and Production of the Halogens

Uses of the Halogens

The Hydrogen Halides

Interhalogen Compounds



# **Table of Contents**

Oxyacids and Oxyanions

## **22.5 Oxygen**

Properties of Oxygen

Production of Oxygen

Uses of Oxygen

Ozone

Oxides

Peroxides and Superoxides

## **22.6 The Other Group 16 Elements: S, Se, Te, and Po**

Occurrence and Production of S, Se, and Te

Properties and Uses of Sulfur, Selenium, and Tellurium

Sulfides

Oxides, Oxyacids, and Oxyanions of Sulfur

## **22.7 Nitrogen**

Properties of Nitrogen

Production and Uses of Nitrogen

Hydrogen Compounds of Nitrogen

Oxides and Oxyacids of Nitrogen

## **22.8 The Other Group 15 Elements: P, As, Sb, and Bi**

Occurrence, Isolation, and Properties of Phosphorus

Phosphorus Halides

Oxy Compounds of Phosphorus

## **22.9 Carbon**

Elemental Forms of Carbon

Oxides of Carbon

Carbonic Acid and Carbonates

Carbides

## **22.10 The Other Group 14 Elements: Si, Ge, Sn, and Pb**

General Characteristics of the Group 14 Elements

Occurrence and Preparation of Silicon

Silicates

Glass

Silicones

## **22.11 Boron**

Chapter Summary and Key Terms

Learning Outcomes

# **Table of Contents**

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

A Closer Look The Hydrogen Economy

Chemistry and Life Nitroglycerin, Nitric Oxide, and Heart Disease

Chemistry and Life Arsenic in Drinking Water

Chemistry Put to Work Carbon Fibers and Composites

## **Chapter 23: Transition Metals and Coordination Chemistry**

### **23.1 The Transition Metals**

Physical Properties

Electron Configurations and Oxidation States

Magnetism

### **23.2 Transition-Metal Complexes**

The Development of Coordination Chemistry: Werners Theory

The MetalLigand Bond

Charges, Coordination Numbers, and Geometries

### **23.3 Common Ligands in Coordination Chemistry**

Metals and Chelates in Living Systems

### **23.4 Nomenclature and Isomerism in Coordination Chemistry**

Isomerism

Constitutional Isomerism

Stereoisomerism

### **23.5 Color and Magnetism in Coordination Chemistry**

Color

Magnetism of Coordination Compounds

### **23.6 Crystal-Field Theory**

Electron Configurations in Octahedral Complexes

Tetrahedral and Square-Planar Complexes

## **Chapter Summary and Key Terms**

Learning Outcomes

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

# **Table of Contents**

A Closer Look Entropy and the Chelate Effect  
Chemistry and Life The Battle for Iron in Living Systems  
A Closer Look Charge-Transfer Color

## **Chapter 24: The Chemistry of Organic Compounds**

### **24.1 General Characteristics of Organic Molecules**

The Structure of Organic Molecules  
The Stabilities of Organic Molecules

### **24.2 An Introduction to Hydrocarbons**

Alkanes  
Applications and Physical Properties of Alkanes  
Homologous Series

### **24.3 Structures of Alkanes**

Alkane Shape and Conformations  
Constitutional/Structural Isomers

### **24.4 Alkane Nomenclature**

### **24.5 Cycloalkanes**

### **24.6 Organic Functional Groups**

### **24.7 Reactions of Alkanes**

Combustion  
Classification of C and H  
Free-Radical Reactions and Electron Movement

### **Chapter Summary and Key Terms**

Key Skills

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Petroleum Products

Chemistry and Life StructureActivity Relationships

A Closer Look Reactivity by Carbon Classification

## **Chapter 25: Stereochemistry of Organic Compounds**

### **25.1 Stereochemistry in Organic Chemistry**

### **25.2 CisTrans Isomerism in Cycloalkanes**

# **Table of Contents**

25.3 Chirality in Organic Compounds

25.4 Measuring Optical Activity

25.5 Absolute Stereochemistry

Using Priority Rules to Find a Stereocenters Absolute Configuration

25.6 Molecules with More than One Stereocenter

Resolution: Separating Enantiomers

Chapter Summary and Key Terms

Key Skills

Key Equations

Exercises

Additional Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Chiral Drugs

## **Chapter 26: Chemistry of Alkenes and Alkynes**

26.1 The Structure of Unsaturated Hydrocarbons

The  $\pi$ -bond

Bonding in Alkenes

Bonding in Alkynes

26.2 Isomerism and Nomenclature

Isomerism in Alkenes The E, Z System

Alkynes

26.3 Arrow Notation and Resonance Structures: Electron Counting

26.4 Electrophilic Addition Reactions

Addition Reactions Involving HX (X = Cl, Br, I)

Addition Reactions Involving H<sub>2</sub>O

Halogenation: Addition of Br<sub>2</sub> and Cl<sub>2</sub>

Halohydrin Formation

26.5 Alkanes from Alkenes: Catalytic Hydrogenation

26.6 Addition Polymerization

Making Polymers

Structure and Physical Properties of Addition Polymers

Chapter Summary and Key Terms

Key Skills

# Table of Contents

Key Equations

Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Terpenes and Isoprene

Chemistry and Life The Chemistry of Vision

A Closer Look Describing Charge

A Closer Look Stereochemistry in Halohydrin Formation

A Closer Look Hydrogenation

Chemistry and Life Recycling Plastics

Chemistry and Life The Accidental Discovery of Teflon®

Chemistry and Life Vulcanization

## Chapter 27: Alcohols, Haloalkanes, and Ethers

### 27.1 Alcohols: Structure, Properties, and Nomenclature

Common Alcohols

Naming Alcohols

Classifying Alcohols

### 27.2 Haloalkanes

### 27.3 Ethers: Structure, Properties, and Nomenclature

Naming Ethers

### 27.4 Reactions of Alcohols

Alkoxides

Basicity of Alcohols

Alcohols to Haloalkanes

Dehydration of Alcohols

### 27.5 Nucleophilic Substitution Reactions of Haloalkanes

### 27.6 Haloalkanes to Alkenes: -Elimination

### 27.7 Substitution versus Elimination

E1 and SN1 Reactions

## Chapter Summary and Key Terms

Key Skills

Key Equations

Exercises

Additional Exercises

# Table of Contents

Integrative Exercises

Design an Experiment

Chemistry and Life Vitamin D

Chemistry and Life The Solubility Nexus

A Closer Look Crown Ethers

A Closer Look Molecularity

A Closer Look Nucleophile or Lewis Base?

Chemistry and Life Polymerization versus Macrocyclization

## Chapter 28: Aldehydes, Ketones, and Carbohydrates

28.1 Aldehydes, Ketones, and the Carbonyl Group

28.2 Preparation of Aldehydes and Ketones

Oxidation of 1° and 2° Alcohols

Ozonolysis

28.3 Reactions of Aldehydes and Ketones

Addition of Carbon Nucleophiles Grignard Reactions

Addition of Nitrogen and Oxygen Nucleophiles: Formation of Imines and Acetals

Reduction Reactions

Cyanohydrins

Tautomerism in Aldehydes and Ketones

Halogenation of Aldehydes and Ketones

28.4 Carbohydrates

Monosaccharides

Cyclic versus Open-Chain Structures

Oligosaccharides and Polysaccharides

Chapter Summary and Key Terms

Key Skills

Key Equations

Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Glucosamine

Chemistry and Life Cyclodextrins

Chemistry and Life Vitamin C

## Chapter 29: Carboxylic Acids and Their Derivatives



# **Table of Contents**

## **29.1 Carboxylic Acids**

Structure, Properties, and Nomenclature

Acidity

## **29.2 Preparation of Carboxylic Acids**

## **29.3 Esters and Esterification**

## **29.4 Fats, Oils, and Waxes**

Soaps and Detergents

## **29.5 Acid Chlorides, Anhydrides, and Nucleophilic Acyl Substitution**

Nucleophilic Acyl Substitution

## **29.6 Condensation Polymerization**

Polymers for Medicine

## **Chapter Summary and Key Terms**

Key Skills

Key Equations

Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Steroids

Chemistry and Life Towards the Plastic Car

Chemistry and Life Biodegradable Sutures

## **Chapter 30: Benzene and its Derivatives**

### **30.1 The Structure of Benzene**

Bonding in Benzene

### **30.2 Isomerism and Nomenclature in Aromatic Compounds**

Phenols

### **30.3 Aromaticity**

### **30.4 Acidity of Phenols**

### **30.5 Electrophilic Aromatic Substitution (EAS) Reactions**

Directing Groups and Substitution Effects

## **Chapter Summary and Key Terms**

Key Skills

Key Equations

Exercises

Integrative Exercises

# Table of Contents

Design an Experiment

Chemistry and Life The Discovery of Liquid Crystals

A Closer Look Organic Dyes

## Chapter 31: Nitrogen-Containing Organic Compounds

### 31.1 Amines and the Amide Bond

Amines

Reactivity of Amines

Synthesis of Amines

Amides

### 31.2 Amino Acids

AcidBase Properties

Reactions Involving Amino Acids

### 31.3 Proteins, Peptides, and Enzymes

Coding Peptides

Protein Structure

Enzymes

Sequencing of Peptides and Proteins

### 31.4 Nucleic Acids and DNA

Chapter Summary and Key Terms

Key Skills

Key Equations

Exercises

Integrative Exercises

Design an Experiment

Chemistry and Life Amines and Amine Hydrochlorides

A Closer Look Sickle-Cell Anemia

Chemistry and Life B Group Vitamins

## Chapter 32: Solving Molecular Structure

### 32.1 The Electromagnetic Spectrum

### 32.2 Infrared (IR) Spectroscopy

The Spring Model

Measuring IR Spectra

### 32.3 Nuclear Magnetic Resonance (NMR) Spectroscopy

Nuclear Magnetic Resonance Frequencies

# **Table of Contents**

The Chemical Shift

Sample Preparation

Interpreting NMR Spectra

Integration

SpinSpin Coupling

<sup>13</sup>C NMR Spectra

## **32.4 Mass Spectrometry**

Electron Impact Ionization Mass Spectrometry

Interpreting Mass Spectra

## **32.5 Compound Identification Using Spectra**

Deducing the Molecular Formula of an Organic Compound

Chemical Wet Testing: Tests for Functional Groups

Using Analysis from Instrumental Techniques

## **Chapter Summary and Key Terms**

Key Skills

Key Equations

Exercises

Integrative Exercises

Design an Experiment

A Closer Look Using Spectroscopic Methods to Measure Reaction Rates

## **Appendices**

Appendix A: Mathematical Operations

Appendix B: Properties of Water

Appendix C: Thermodynamic Quantities for Selected Substances at 298.15 K (25 °C)

Appendix D: Aqueous Equilibrium Constants

Appendix E: Standard Reduction Potentials at 25 °C

## **Answers to Selected Exercises**

## **Answers to Go Figure**

## **Answers to Selected Practice Exercises**

## **Glossary**

## **Photo and Art Credits**

## **Index**

## **Table of Contents**

Common Ions

Fundamental Constants

Useful Conversion Factors and Relationships

Color Chart for Common Elements