

# CONTENTS

## 1 FUNDAMENTAL CONCEPTS AND UNITS OF MEASUREMENT 1

- 1.1 Chemistry is important for anyone studying the sciences 2
- 1.2 The scientific method helps us build models of nature 3
- 1.3 Matter is composed of elements, compounds, and mixtures 5
- 1.4 Properties of matter can be classified in different ways 8
- 1.5 Measurements are essential to describe properties 9
- 1.6 Measurements always contain some uncertainty 18
- 1.7 Units can be converted using the factor-label method 21
- 1.8 Density is a useful intensive property 25
- TOOLS FOR PROBLEM SOLVING** 29
- QUESTIONS, PROBLEMS, AND EXERCISES** 29

## 2 ELEMENTS, COMPOUNDS, AND CHEMICAL REACTIONS 34

- 2.1 Elements and atoms are described by Dalton's atomic theory 35
- 2.2 Atoms are composed of subatomic particles 40
- 2.3 The periodic table is used to organize and correlate facts 47
- 2.4 Elements can be metals, nonmetals, or metalloids 51
- 2.5 Formulas and equations describe substances and their reactions 54
- 2.6 Molecular compounds contain neutral particles called molecules 59
- 2.7 Ionic compounds are composed of charged particles called ions 62
- 2.8 The formulas of many ionic compounds can be predicted 65
- 2.9 Molecular and ionic compounds are named following a system 70
- TOOLS FOR PROBLEM SOLVING** 79
- QUESTIONS, PROBLEMS, AND EXERCISES** 80

## 3 THE MOLE: RELATING THE MICROSCOPIC WORLD OF ATOMS TO LABORATORY MEASUREMENTS 86

- 3.1 The mole conveniently links mass to number of atoms or molecules 87
- 3.2 Chemical formulas relate amounts of substances in a compound 91

- 3.3 Chemical formulas can be determined from experimental mass measurements 94
- 3.4 Chemical equations link amounts of substances in a reaction 103
- 3.5 The reactant in shortest supply limits the amount of product that can form 110
- 3.6 The predicted amount of product is not always obtained experimentally 113
- TOOLS FOR PROBLEM SOLVING** 116
- QUESTIONS, PROBLEMS, AND EXERCISES** 117

## CHAPTERS 1-3 BRINGING IT TOGETHER 125

## 4 REACTIONS OF IONS AND MOLECULES IN AQUEOUS SOLUTIONS 127

- 4.1 Special terminology applies to solutions 128
- 4.2 Ionic compounds conduct electricity when dissolved in water 129
- 4.3 Acids and bases are classes of compounds with special properties 135
- 4.4 Naming acids and bases follows a system 143
- 4.5 Ionic reactions can often be predicted 146
- 4.6 The composition of a solution is described by its concentration 154
- 4.7 Molarity is used for problems in solution stoichiometry 159
- 4.8 Chemical analysis and titration are applications of solution stoichiometry 163
- TOOLS FOR PROBLEM SOLVING** 168
- QUESTIONS, PROBLEMS, AND EXERCISES** 169

## 5 OXIDATION-REDUCTION REACTIONS 175

- 5.1 Oxidation-reduction reactions involve electron transfer 176
- 5.2 The ion-electron method creates balanced net ionic equations for redox reactions 182
- 5.3 Metals are oxidized when they react with acids 187
- 5.4 A more active metal will displace a less active one from its compounds 189
- 5.5 Molecular oxygen is a powerful oxidizing agent 193
- 5.6 Redox reactions follow the same stoichiometric principles as other reactions 196
- TOOLS FOR PROBLEM SOLVING** 200
- QUESTIONS, PROBLEMS, AND EXERCISES** 200

**6 ENERGY AND CHEMICAL CHANGE 207**

- 6.1** An object has energy if it is capable of doing work 208
- 6.2** Internal energy is the total energy of an object's molecules 211
- 6.3** Heat can be determined by measuring temperature changes 213
- 6.4** Energy is absorbed or released during most chemical reactions 218
- 6.5** Heats of reaction are measured at constant volume or constant pressure 219
- 6.6** Thermochemical equations are chemical equations that quantitatively include heat 227
- 6.7** Thermochemical equations can be combined because enthalpy is a state function 229
- 6.8** Tabulated standard heats of reaction can be used to predict any heat of reaction using Hess's law 235

**TOOLS FOR PROBLEM SOLVING** 241**QUESTIONS, PROBLEMS, AND EXERCISES** 242**CHAPTERS 4-6 BRINGING IT TOGETHER 247****7 THE QUANTUM MECHANICAL ATOM 250**

- 7.1** Electromagnetic radiation provides the clue to the electronic structures of atoms 251
- 7.2** Atomic line spectra are evidence that electrons in atoms have quantized energies 259
- 7.3** Electrons have properties of both particles and waves 263
- 7.4** Electron spin affects the distribution of electrons among orbitals in atoms 271
- 7.5** The ground state electron configuration is the lowest energy distribution of electrons among orbitals 273
- 7.6** Electron configurations explain the structure of the periodic table 275
- 7.7** Quantum theory predicts the shapes of atomic orbitals 281
- 7.8** Atomic properties correlate with an atom's electron configuration 284

**TOOLS FOR PROBLEM SOLVING** 293**QUESTIONS, PROBLEMS, AND EXERCISES** 293**8 CHEMICAL BONDING: GENERAL CONCEPTS 298**

- 8.1** Electron transfer leads to the formation of ionic compounds 299
- 8.2** Lewis symbols help keep track of valence electrons 306
- 8.3** Covalent bonds are formed by electron sharing 308
- 8.4** Covalent bonds can have partial charges at opposite ends 312

- 8.5** The reactivities of metals and nonmetals can be related to their electronegativities 316
- 8.6** Drawing Lewis structures is a necessary skill 317
- 8.7** Resonance applies when a single Lewis structure fails 327

**TOOLS FOR PROBLEM SOLVING** 332**QUESTIONS, PROBLEMS, AND EXERCISES** 333**9 CHEMICAL BONDING AND MOLECULAR STRUCTURE 338**

- 9.1** Molecules are three-dimensional with shapes that are built from five basic arrangements 339
- 9.2** Molecular shapes are predicted using the VSEPR model 341
- 9.3** Molecular symmetry affects the polarity of molecules 349
- 9.4** Valence bond theory explains bonding as an overlap of atomic orbitals 352
- 9.5** Hybrid orbitals are used to explain experimental molecular geometries 355
- 9.6** Hybrid orbitals can be used to describe multiple bonds 365
- 9.7** Molecular orbital theory explains bonding as constructive interference of atomic orbitals 372
- 9.8** Molecular orbital theory uses delocalized orbitals to describe molecules with resonance structures 378

**TOOLS FOR PROBLEM SOLVING** 380**QUESTIONS, PROBLEMS, AND EXERCISES** 382**CHAPTERS 7-9 BRINGING IT TOGETHER 387****10 PROPERTIES OF GASES 389**

- 10.1** Familiar properties of gases can be explained at the molecular level 390
- 10.2** Pressure is a measured property of gases 391
- 10.3** The gas laws summarize experimental observations 396
- 10.4** Gas volumes can be used in solving stoichiometry problems 401
- 10.5** The ideal gas law relates  $P$ ,  $V$ ,  $T$ , and the number of moles of gas,  $n$  405
- 10.6** In a mixture each gas exerts its own partial pressure 412
- 10.7** Effusion and diffusion in gases leads to Graham's law 417
- 10.8** The kinetic molecular theory explains the gas laws 419
- 10.9** Real gases don't obey the ideal gas law perfectly 423

**xxvi Contents**

**TOOLS FOR PROBLEM SOLVING** 426  
**QUESTIONS, PROBLEMS, AND EXERCISES** 427

**11 INTERMOLECULAR ATTRACTIONS AND THE PROPERTIES OF LIQUIDS AND SOLIDS** 432

- 11.1** Gases, liquids, and solids differ because intermolecular forces depend on the distances between molecules 433  
**11.2** Intermolecular attractions involve electrical charges 433  
**11.3** Intermolecular forces and tightness of packing affect the physical properties of liquids and solids 441  
**11.4** Changes of state lead to dynamic equilibria 447  
**11.5** Vapor pressures of liquids and solids are controlled by temperature and intermolecular attractions 448  
**11.6** Boiling occurs when a liquid's vapor pressure equals atmospheric pressure 450  
**11.7** Energy changes occur during changes of state 452  
**11.8** Changes in a dynamic equilibrium can be analyzed using Le Châtelier's principle 455  
**11.9** Crystalline solids have an ordered internal structure 456  
**11.10** X-Ray diffraction is used to study crystal structures 462  
**11.11** Physical properties of solids are related to their crystal types 465  
**11.12** Phase diagrams graphically represent pressure–temperature relationships 467  
**TOOLS FOR PROBLEM SOLVING** 473  
**QUESTIONS, PROBLEMS, AND EXERCISES** 474

**12 PROPERTIES OF SOLUTIONS; MIXTURES OF SUBSTANCES AT THE MOLECULAR LEVEL** 480

- 12.1** Substances mix spontaneously when there is no energy barrier to mixing 481  
**12.2** Heats of solution come from unbalanced intermolecular attractions 483  
**12.3** A substance's solubility changes with temperature 488  
**12.4** Gases become more soluble at higher pressures 489  
**12.5** Molarity changes with temperature; molality, weight percentages, and mole fractions do not 491  
**12.6** Solute lowers the vapor pressure of a solvent 496  
**12.7** Solutions have lower melting points and higher boiling points than pure solvents 500  
**12.8** Osmosis is a flow of solvent through a semipermeable membrane due to unequal concentrations 503  
**12.9** Ionic solutes affect colligative properties differently from nonionic solutes 508  
**TOOLS FOR PROBLEM SOLVING** 512  
**QUESTIONS, PROBLEMS, AND EXERCISES** 513

**CHAPTERS 10–12 BRINGING IT TOGETHER** 517

**13 KINETICS: THE STUDY OF RATES OF REACTION** 519

- 13.1** Five factors affect reaction rates 520  
**13.2** Rates of reaction are measured by monitoring change in concentration over time 522  
**13.3** Rate laws give reaction rate as a function of reactant concentrations 526  
**13.4** Integrated rate laws give concentration as a function of time 534  
**13.5** Reaction rate theories explain experimental rate laws in terms of molecular collisions 543  
**13.6** Activation energies are measured by fitting experimental data to the Arrhenius equation 548  
**13.7** Experimental rate laws can be used to support or reject proposed mechanisms for a reaction 551  
**13.8** Catalysts change reaction rates by providing alternative paths between reactants and products 557  
**TOOLS FOR PROBLEM SOLVING** 560  
**QUESTIONS, PROBLEMS, AND EXERCISES** 561

**14 CHEMICAL EQUILIBRIUM: GENERAL CONCEPTS** 568

- 14.1** Dynamic equilibrium is achieved when the rates of forward and reverse processes become equal 569  
**14.2** A law relating equilibrium concentrations can be derived from the balanced chemical equation for a reaction 571  
**14.3** Equilibrium laws for gaseous reactions can be written in terms of either concentrations or pressures 575  
**14.4** Heterogeneous equilibria involve reaction mixtures with more than one phase 578  
**14.5** When  $K$  is large, the position of equilibrium lies toward the products 579  
**14.6** Le Châtelier's principle tells us how a chemical equilibrium responds when disturbed 581  
**14.7** Equilibrium concentrations can be used to predict equilibrium constants, and vice versa 585  
**TOOLS FOR PROBLEM SOLVING** 598  
**QUESTIONS, PROBLEMS, AND EXERCISES** 599

**15 ACIDS AND BASES: A SECOND LOOK** 605

- 15.1** Brønsted-Lowry acids and bases exchange protons 606  
**15.2** Strengths of Brønsted acids and bases follow periodic trends 611  
**15.3** Lewis acids and bases involve coordinate covalent bonds 619

**15.4** Elements and their oxides demonstrate acid-base properties 623

**15.5** pH is a measure of the acidity of a solution 625

**15.6** Strong acids and bases are fully dissociated in solution 634

**TOOLS FOR PROBLEM SOLVING** 637

**QUESTIONS, PROBLEMS, AND EXERCISES** 638

## **16 EQUILIBRIA IN SOLUTIONS OF WEAK ACIDS AND BASES 642**

**16.1** Ionization constants can be defined for weak acids and bases 643

**16.2** Calculations can involve finding or using  $K_a$  and  $K_b$  649

**16.3** Salt solutions are not neutral if the ions are weak acids or bases 657

**16.4** Simplifications fail for some equilibrium calculations 662

**16.5** Buffers enable the control of pH 666

**16.6** Polyprotic acids ionize in two or more steps 673

**16.7** Acid-base titrations have sharp changes in pH at the equivalence point 678

**TOOLS FOR PROBLEM SOLVING** 686

**QUESTIONS, PROBLEMS, AND EXERCISES** 687

## **17 SOLUBILITY AND SIMULTANEOUS EQUILIBRIA 692**

**17.1** An insoluble salt is in equilibrium with the solution around it 693

**17.2** Solubility equilibria of metal oxides and sulfides involve reaction with water 704

**17.3** Metal ions can be separated by selective precipitation 707

**17.4** Complex ions participate in equilibria in aqueous solutions 712

**17.5** Complex ion formation increases the solubility of a salt 714

**TOOLS FOR PROBLEM SOLVING** 717

**QUESTIONS, PROBLEMS, AND EXERCISES** 718

## **CHAPTERS 13-17 BRINGING IT TOGETHER 723**

## **18 THERMODYNAMICS 726**

**18.1** Internal energy can be transferred as heat or work, but it cannot be created or destroyed 727

**18.2** A spontaneous change is a change that continues without outside intervention 730

**18.3** Spontaneous processes tend to proceed from states of lower probability to states of higher probability 732

**18.4** All spontaneous processes increase the total entropy of the universe 737

**18.5** The third law of thermodynamics makes experimental measurement of absolute entropies possible 740

**18.6** The standard free energy change,  $\Delta G^\circ$ , is  $\Delta G$  at standard conditions 743

**18.7**  $\Delta G$  is the maximum amount of work that can be done by a process 745

**18.8**  $\Delta G$  is zero when a system is at equilibrium 748

**18.9** Equilibrium constants can be estimated from standard free energy changes 753

**18.10** Bond energies can be estimated from reaction enthalpy changes 757

**TOOLS FOR PROBLEM SOLVING** 762

**QUESTIONS, PROBLEMS, AND EXERCISES** 763

## **19 ELECTROCHEMISTRY 769**

**19.1** Galvanic cells use redox reactions to generate electricity 770

**19.2** Cell potentials can be related to reduction potentials 775

**19.3** Standard reduction potentials can predict spontaneous reactions 782

**19.4** Cell potentials are related to free energy changes 787

**19.5** Concentrations in a galvanic cell affect the cell potential 790

**19.6** Electrolysis uses electrical energy to cause chemical reactions 796

**19.7** Stoichiometry of electrochemical reactions involves electric current and time 802

**19.8** Practical applications of electrochemistry 805

**TOOLS FOR PROBLEM SOLVING** 814

**QUESTIONS, PROBLEMS, AND EXERCISES** 815

## **20 NUCLEAR REACTIONS AND THEIR ROLE IN CHEMISTRY 820**

**20.1** Mass and energy are conserved in all of their forms 821

**20.2** The energy required to break a nucleus into separate nucleons is called the nuclear binding energy 822

**20.3** Radioactivity is an emission of particles and/or electromagnetic radiation by unstable atomic nuclei 824

**20.4** Stable isotopes fall within a “band of stability” on a plot based on numbers of protons and neutrons 830

**20.5** Transmutation is the change of one isotope into another 834

**20.6** How is radiation measured? 836

**20.7** Radionuclides have medical and analytical applications 840

**20.8** Nuclear fission and nuclear fusion release large amounts of energy 842

**xxviii Contents**

**TOOLS FOR PROBLEM SOLVING** 848  
**QUESTIONS, PROBLEMS, AND EXERCISES** 849

**21 NONMETALS, METALLOIDS, METALS,  
 AND METAL COMPLEXES 854**

- 21.1** Nonmetals and metalloids are found as free elements and in compounds 855
- 21.2** Nonmetallic elements in their free states have structures of varying complexity 858
- 21.3** Metals are prepared from compounds by reduction 863
- 21.4** Metallurgy is the science and technology of metals 867
- 21.5** Complex ions are formed by many metals 871
- 21.6** The nomenclature of metal complexes follows an extension of the rules developed earlier 876
- 21.7** Coordination number and structure are often related 878
- 21.8** Isomers of coordination complexes are compounds with the same formula but different structures 880
- 21.9** Bonding in transition metal complexes involves *d* orbitals 884
- 21.10** Metal ions serve critical functions in biological systems 890

**TOOLS FOR PROBLEM SOLVING** 894  
**QUESTIONS, PROBLEMS, AND EXERCISES** 894

**22 ORGANIC COMPOUNDS, POLYMERS,  
 AND BIOCHEMICALS 900**

- 22.1** Organic chemistry is the study of carbon compounds 901
- 22.2** Hydrocarbons consist of only C and H atoms 906
- 22.3** Ethers and alcohols are organic derivatives of water 913
- 22.4** Amines are organic derivatives of ammonia 917
- 22.5** Organic compounds with carbonyl groups include aldehydes, ketones, and carboxylic acids 918
- 22.6** Polymers are composed of many repeating molecular units 922
- 22.7** Most biochemicals are organic compounds 930
- 22.8** Nucleic acids carry our genetic information 939

**TOOLS FOR PROBLEM SOLVING** 946  
**QUESTIONS, PROBLEMS, AND EXERCISES** 947

**CHAPTERS 18-22 BRINGING IT TOGETHER 954**

**APPENDICES**

- A. Electron Configurations of the Elements A-1
- B. Answers to Practice Exercises and Selected Review Exercises A-2
- C. Tables of Selected Data A-21

**GLOSSARY G-1**

**INDEX 1-1**