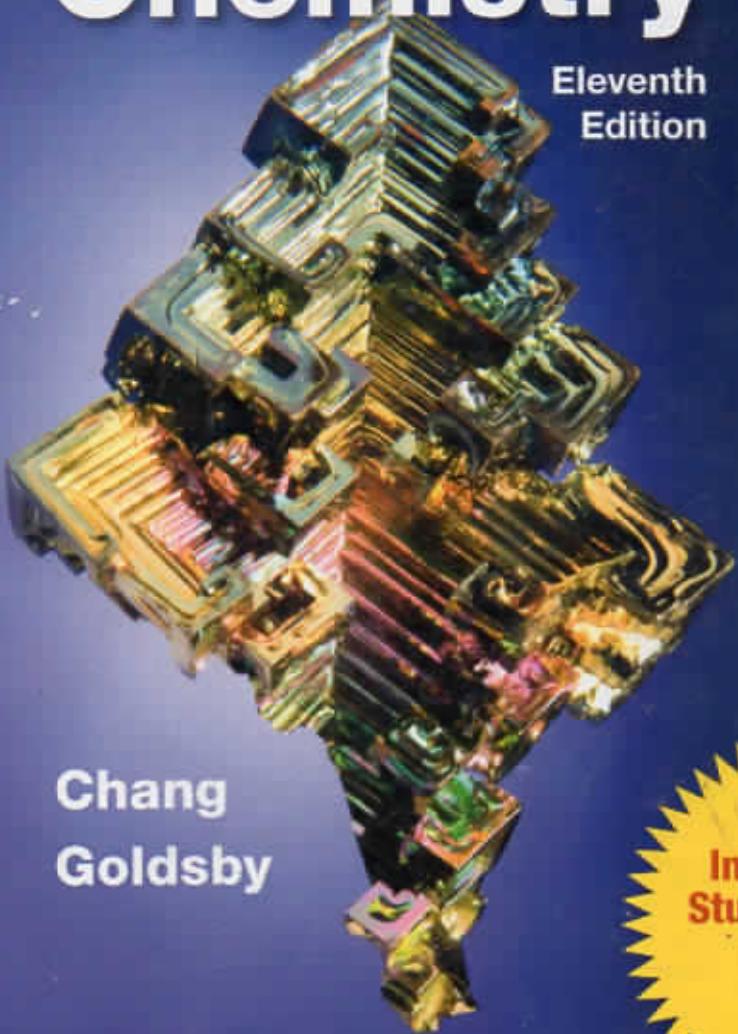


# Chemistry

Eleventh  
Edition



Chang  
Goldsby

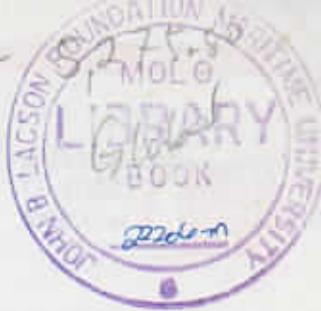
This  
International  
Student Edition  
is for use  
outside  
the U.S.

MCGRAW-HILL INTERNATIONAL EDITION



C  
940  
C495  
2013

Chen  
Bartolomeo



Eleventh Edition

# Chemistry

Raymond Chang

*Williams College*

Kenneth A. Goldsby

*Florida State University*



# Contents

*List of Applications* xix

*List of Animations* xx

*Preface* xxi

*Setting the Stage for Learning* xxviii

*A Note to the Student* xxxiii



## Chemistry: The Study of Change 1

**1.1** Chemistry: A Science for the Twenty-First Century 2

**1.2** The Study of Chemistry 2

**1.3** The Scientific Method 4

### CHEMISTRY *in Action*

Primordial Helium and the Big Bang Theory 6

**1.4** Classifications of Matter 6

**1.5** The Three States of Matter 9

**1.6** Physical and Chemical Properties of Matter 10

**1.7** Measurement 12

### CHEMISTRY *in Action*

The Importance of Units 17

**1.8** Handling Numbers 18

**1.9** Dimensional Analysis in Solving Problems 23

**1.10** Real-World Problem Solving: Information, Assumptions, and Simplifications 27

### Key Equations 28

*Summary of Facts & Concepts* 29

*Key Words* 29

*Questions & Problems* 29

### CHEMICAL Mystery

The Disappearance of the Dinosaurs 36



## Atoms, Molecules, and Ions 38

- 2.1** The Atomic Theory 39
- 2.2** The Structure of the Atom 40
- 2.3** Atomic Number, Mass Number, and Isotopes 46
- 2.4** The Periodic Table 48

### *CHEMISTRY in Action*

Distribution of Elements on Earth and in Living Systems 49

- 2.5** Molecules and Ions 50
- 2.6** Chemical Formulas 52
- 2.7** Naming Compounds 56
- 2.8** Introduction to Organic Compounds 65

*Key Equation* 67

*Summary of Facts & Concepts* 67

*Key Words* 67

*Questions & Problems* 68



## Mass Relationships in Chemical Reactions 75

- 3.1** Atomic Mass 76
- 3.2** Avogadro's Number and the Molar Mass of an Element 77
- 3.3** Molecular Mass 81
- 3.4** The Mass Spectrometer 84
- 3.5** Percent Composition of Compounds 85
- 3.6** Experimental Determination of Empirical Formulas 88
- 3.7** Chemical Reactions and Chemical Equations 90
- 3.8** Amounts of Reactants and Products 95
- 3.9** Limiting Reagents 99
- 3.10** Reaction Yield 103

### *CHEMISTRY in Action*

Chemical Fertilizers 105

*Key Equations* 106

*Summary of Facts & Concepts* 106

*Key Words* 107

*Questions & Problems* 107



## Reactions in Aqueous Solutions 118

- 4.1** General Properties of Aqueous Solutions 119  
**4.2** Precipitation Reactions 121

*CHEMISTRY in Action*  
An Undesirable Precipitation Reaction 126

- 4.3** Acid-Base Reactions 126  
**4.4** Oxidation-Reduction Reactions 132

*CHEMISTRY in Action*  
Breathalyzer 144

- 4.5** Concentration of Solutions 145  
**4.6** Gravimetric Analysis 149  
**4.7** Acid-Base Titrations 151  
**4.8** Redox Titrations 155

*CHEMISTRY in Action*  
Metal from the Sea 156

*Key Equations 157*  
*Summary of Facts & Concepts 157*  
*Key Words 158*  
*Questions & Problems 158*

**CHEMICAL Mystery**  
Who Killed Napoleon? 170



## Gases 172

- 5.1** Substances That Exist as Gases 173  
**5.2** Pressure of a Gas 174  
**5.3** The Gas Laws 178  
**5.4** The Ideal Gas Equation 184  
**5.5** Gas Stoichiometry 193  
**5.6** Dalton's Law of Partial Pressures 195

*CHEMISTRY in Action*  
Scuba Diving and the Gas Laws 200

- 5.7** The Kinetic Molecular Theory of Gases 202

*CHEMISTRY in Action*  
Super Cold Atoms 208

- 5.8** Deviation from Ideal Behavior 210

*Key Equations 213*  
*Summary of Facts & Concepts 214*  
*Key Words 214*  
*Questions & Problems 215*

**CHEMICAL Mystery**  
Out of Oxygen 228



## Thermochemistry 230

- 6.1** The Nature of Energy and Types of Energy 231  
**6.2** Energy Changes in Chemical Reactions 232  
**6.3** Introduction to Thermodynamics 234
- CHEMISTRY in Action*  
Making Snow and Inflating a Bicycle Tire 240
- 6.4** Enthalpy of Chemical Reactions 240  
**6.5** Calorimetry 246
- CHEMISTRY in Action*  
White Fat Cells, Brown Fat Cells, and a Potential Cure for Obesity 250
- 6.6** Standard Enthalpy of Formation and Reaction 254
- CHEMISTRY in Action*  
How a Bombardier Beetle Defends Itself 257
- 6.7** Heat of Solution and Dilution 260
- Key Equations* 263  
*Summary of Facts & Concepts* 263  
*Key Words* 263  
*Questions & Problems* 264
- CHEMICAL Mystery*  
The Exploding Tire 274



## Quantum Theory and the Electronic Structure of Atoms 276

- 7.1** From Classical Physics to Quantum Theory 277  
**7.2** The Photoelectric Effect 281  
**7.3** Bohr's Theory of the Hydrogen Atom 284  
**7.4** The Dual Nature of the Electron 289
- CHEMISTRY in Action*  
Laser—The Splendid Light 290
- 7.5** Quantum Mechanics 293
- CHEMISTRY in Action*  
Electron Microscopy 294
- 7.6** Quantum Numbers 297  
**7.7** Atomic Orbitals 299  
**7.8** Electron Configuration 303

**7.9** The Building-Up Principle 310*CHEMISTRY in Action*

Quantum Dots 314

*Key Equations* 315*Summary of Facts & Concepts* 316*Key Words* 317*Questions & Problems* 317*CHEMICAL Mystery*

Discovery of Helium and the Rise and Fall of Coronium 326



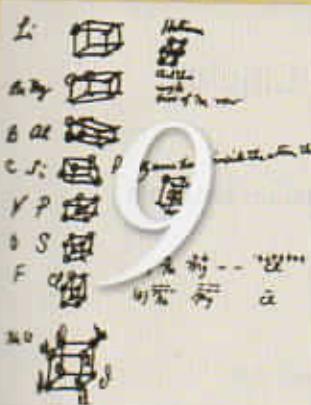
## Periodic Relationships Among the Elements 328

**8.1** Development of the Periodic Table 329**8.2** Periodic Classification of the Elements 331**8.3** Periodic Variation in Physical Properties 335**8.4** Ionization Energy 342*CHEMISTRY in Action*

The Third Liquid Element? 343

**8.5** Electron Affinity 347**8.6** Variation in Chemical Properties of the Representative Elements 349*CHEMISTRY in Action*

Discovery of the Noble Gases 360

*Key Equation* 361*Summary of Facts & Concepts* 361*Key Words* 362*Questions & Problems* 362

## Chemical Bonding I: Basic Concepts 370

**9.1** Lewis Dot Symbols 371**9.2** The Ionic Bond 372**9.3** Lattice Energy of Ionic Compounds 374*CHEMISTRY in Action*

Sodium Chloride—A Common and Important Ionic Compound 378

**9.4** The Covalent Bond 379**9.5** Electronegativity 382**9.6** Writing Lewis Structures 386**9.7** Formal Charge and Lewis Structure 389

- 9.8** The Concept of Resonance 392  
**9.9** Exceptions to the Octet Rule 394

*CHEMISTRY in Action*  
 Just Say NO 399

- 9.10** Bond Enthalpy 400  
*Key Equation* 405  
*Summary of Facts & Concepts* 405  
*Key Words* 405  
*Questions & Problems* 405



## Chemical Bonding II: Molecular Geometry and Hybridization of Atomic Orbitals 414

- 10.1** Molecular Geometry 415  
**10.2** Dipole Moment 425

*CHEMISTRY in Action*  
 Microwave Ovens—Dipole Moments at Work 428

- 10.3** Valence Bond Theory 431  
**10.4** Hybridization of Atomic Orbitals 433  
**10.5** Hybridization in Molecules Containing Double and Triple Bonds 442  
**10.6** Molecular Orbital Theory 445  
**10.7** Molecular Orbital Configurations 448  
**10.8** Delocalized Molecular Orbitals 454

*CHEMISTRY in Action*  
 Buckyball, Anyone? 456

*Key Equations* 458  
*Summary of Facts & Concepts* 458  
*Key Words* 458  
*Questions & Problems* 459



## Intermolecular Forces and Liquids and Solids 467

- 11.1** The Kinetic Molecular Theory of Liquids and Solids 468  
**11.2** Intermolecular Forces 469  
**11.3** Properties of Liquids 475  
**11.4** Crystal Structure 478

*CHEMISTRY in Action*  
 Why Do Lakes Freeze from the Top Down? 479

- 11.5** X-Ray Diffraction by Crystals 486

**11.6** Types of Crystals 488**CHEMISTRY *In Action***

High-Temperature Superconductors 490

**CHEMISTRY *In Action***

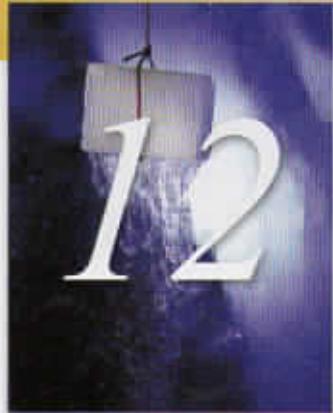
And All for the Want of a Button 494

**11.7** Amorphous Solids 494**11.8** Phase Changes 495**11.9** Phase Diagrams 505**CHEMISTRY *In Action***

Hard-Boiling an Egg on a Mountaintop, Pressure Cookers, and Ice Skating 507

**CHEMISTRY *In Action***

Liquid Crystals 508

**Key Equations 510****Summary of Facts & Concepts 510****Key Words 511****Questions & Problems 511**

## Physical Properties of Solutions 520

**12.1** Types of Solutions 521**12.2** A Molecular View of the Solution Process 522**12.3** Concentration Units 524**12.4** The Effect of Temperature on Solubility 529**12.5** The Effect of Pressure on the Solubility of Gases 531**CHEMISTRY *In Action***

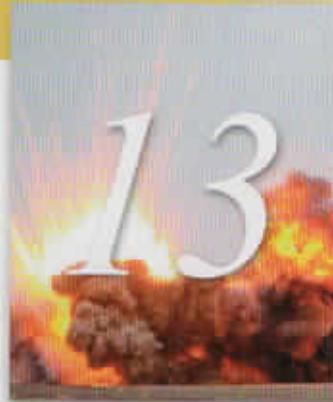
The Killer Lake 533

**12.6** Colligative Properties of Nonelectrolyte Solutions 534**12.7** Colligative Properties of Electrolyte Solutions 546**CHEMISTRY *In Action***

Dialysis 548

**12.8** Colloids 548**Key Equations 551****Summary of Facts & Concepts 551****Key Words 552****Questions & Problems 552****CHEMICAL Mystery**

The Wrong Knife 562



## Chemical Kinetics 564

**13.1** The Rate of a Reaction 565

**13.2** The Rate Law 573

**13.3** The Relation Between Reactant Concentration and Time 577

**CHEMISTRY in Action**

Radiocarbon Dating 588

**13.4** Activation Energy and Temperature Dependence of Rate Constants 590

**13.5** Reaction Mechanisms 596

**13.6** Catalysis 601

**CHEMISTRY in Action**

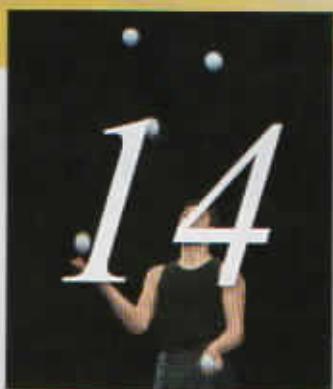
Pharmacokinetics 608

*Key Equations* 610

*Summary of Facts & Concepts* 610

*Key Words* 611

*Questions & Problems* 611



## Chemical Equilibrium 623

**14.1** The Concept of Equilibrium and the Equilibrium Constant 624

**14.2** Writing Equilibrium Constant Expressions 627

**14.3** The Relationship Between Chemical Kinetics and Chemical Equilibrium 639

**14.4** What Does the Equilibrium Constant Tell Us? 640

**14.5** Factors That Affect Chemical Equilibrium 646

**CHEMISTRY in Action**

Life at High Altitudes and Hemoglobin Production 653

**CHEMISTRY in Action**

The Haber Process 654

*Key Equations* 656

*Summary of Facts & Concepts* 656

*Key Words* 657

*Questions & Problems* 657



## Acids and Bases 668

**15.1** Brønsted Acids and Bases 669

**15.2** The Acid-Base Properties of Water 670

**15.3** pH—A Measure of Acidity 672

**15.4** Strength of Acids and Bases 675

**15.5** Weak Acids and Acid Ionization Constants 679

**15.6** Weak Bases and Base Ionization Constants 687

**15.7** The Relationship Between the Ionization Constants of Acids and Their Conjugate Bases 689

- 15.8** Diprotic and Polyprotic Acids 690  
**15.9** Molecular Structure and the Strength of Acids 694  
**15.10** Acid-Base Properties of Salts 698  
**15.11** Acid-Base Properties of Oxides and Hydroxides 704  
**15.12** Lewis Acids and Bases 706

**CHEMISTRY *In Action***

Antacids and the pH Balance in Your Stomach 708

*Key Equations* 710

*Summary of Facts & Concepts* 711

*Key Words* 711

*Questions & Problems* 711

**CHEMICAL Mystery**

Decaying Papers 720



## Acid-Base Equilibria and Solubility Equilibria 722

- 16.1** Homogeneous versus Heterogeneous Solution Equilibria 723  
**16.2** The Common Ion Effect 723  
**16.3** Buffer Solutions 726  
**16.4** Acid-Base Titrations 732
- CHEMISTRY *In Action***
- Maintaining the pH of Blood 734
- 16.5** Acid-Base Indicators 741  
**16.6** Solubility Equilibria 744  
**16.7** Separation of Ions by Fractional Precipitation 751  
**16.8** The Common Ion Effect and Solubility 753  
**16.9** pH and Solubility 755  
**16.10** Complex Ion Equilibria and Solubility 758

**CHEMISTRY *In Action***

How an Eggshell Is Formed 762

- 16.11** Application of the Solubility Product Principle to Qualitative Analysis 763

*Key Equation* 765

*Summary of Facts & Concepts* 766

*Key Words* 766

*Questions & Problems* 766

**CHEMICAL Mystery**

A Hard-Boiled Snack 776



## Entropy, Free Energy, and Equilibrium 778

**17.1** The Three Laws of Thermodynamics 779

**17.2** Spontaneous Processes 779

**17.3** Entropy 780

**17.4** The Second Law of Thermodynamics 785

**17.5** Gibbs Free Energy 791

### CHEMISTRY *in Action*

The Efficiency of Heat Engines 792

**17.6** Free Energy and Chemical Equilibrium 798

**17.7** Thermodynamics in Living Systems 802

### CHEMISTRY *in Action*

The Thermodynamics of a Rubber Band 803

*Key Equations* 805

*Summary of Facts & Concepts* 805

*Key Words* 805

*Questions & Problems* 806



## Electrochemistry 814

**18.1** Redox Reactions 815

**18.2** Galvanic Cells 818

**18.3** Standard Reduction Potentials 820

**18.4** Thermodynamics of Redox Reactions 826

**18.5** The Effect of Concentration of Cell Emf 829

**18.6** Batteries 834

### CHEMISTRY *in Action*

Bacteria Power 839

**18.7** Corrosion 840

**18.8** Electrolysis 843

### CHEMISTRY *in Action*

Dental Filling Discomfort 848

*Key Equations* 850

*Summary of Facts & Concepts* 850

*Key Words* 851

*Questions & Problems* 851

### CHEMICAL Mystery

Tainted Water 862



## Nuclear Chemistry 864

**19.1** The Nature of Nuclear Reactions 865

**19.2** Nuclear Stability 867

**19.3** Natural Radioactivity 872

**19.4** Nuclear Transmutation 876

**19.5** Nuclear Fission 879

*CHEMISTRY in Action*

Nature's Own Fission Reactor 884

**19.6** Nuclear Fusion 885

**19.7** Uses of Isotopes 888

**19.8** Biological Effects of Radiation 890

*CHEMISTRY in Action*

Food Irradiation 892

*Key Equations* 892

*CHEMISTRY in Action*

Boron Neutron Capture Therapy 893

*Summary of Facts & Concepts* 893

*Key Words* 894

*Questions & Problems* 894

*CHEMICAL Mystery*

The Art Forgery of the Twentieth Century 900



## Chemistry in the Atmosphere 902

**20.1** Earth's Atmosphere 903

**20.2** Phenomena in the Outer Layers of the Atmosphere 906

**20.3** Depletion of Ozone in the Stratosphere 908

**20.4** Volcanoes 913

**20.5** The Greenhouse Effect 914

**20.6** Acid Rain 918

**20.7** Photochemical Smog 921

**20.8** Indoor Pollution 923

*Summary of Facts & Concepts* 926

*Key Words* 927

*Questions & Problems* 927



# 21

## Metallurgy and the Chemistry of Metals 932

- 21.1** Occurrence of Metals 933
- 21.2** Metallurgical Processes 934
- 21.3** Band Theory of Electrical Conductivity 941
- 21.4** Periodic Trends in Metallic Properties 943
- 21.5** The Alkali Metals 944
- 21.6** The Alkaline Earth Metals 948
- 21.7** Aluminum 950

**CHEMISTRY in Action**

Recycling Aluminum 952

*Summary of Facts & Concepts* 954

*Key Words* 954

*Questions & Problems* 954



## Nonmetallic Elements and Their Compounds 958

- 22.1** General Properties of Nonmetals 959
- 22.2** Hydrogen 960

**CHEMISTRY in Action**

Metallic Hydrogen 964

- 22.3** Carbon 965

**CHEMISTRY in Action**

Synthetic Gas from Coal 968

- 22.4** Nitrogen and Phosphorus 969

**CHEMISTRY in Action**

Ammonium Nitrate—The Explosive Fertilizer 976

- 22.5** Oxygen and Sulfur 977

- 22.6** The Halogens 984

*Summary of Facts & Concepts* 991

*Key Words* 991

*Questions & Problems* 992



## Transition Metals Chemistry and Coordination Compounds 996

- 23.1** Properties of the Transition Metals 997
- 23.2** Chemistry of Iron and Copper 1000
- 23.3** Coordination Compounds 1002
- 23.4** Structure of Coordination Compounds 1007
- 23.5** Bonding in Coordination Compounds: Crystal Field Theory 1011
- 23.6** Reactions of Coordination Compounds 1017

*CHEMISTRY in Action*

Coordination Compounds in Living Systems 1018

- 23.7** Applications of Coordination Compounds 1018

*CHEMISTRY in Action*

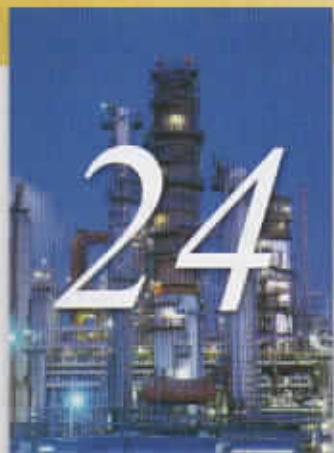
Cisplatin—The Anticancer Drug 1020

*Key Equation* 1022

*Summary of Facts & Concepts* 1022

*Key Words* 1022

*Questions & Problems* 1023



## Organic Chemistry 1027

- 24.1** Classes of Organic Compounds 1028
- 24.2** Aliphatic Hydrocarbons 1028

*CHEMISTRY in Action*

Ice That Burns 1040

- 24.3** Aromatic Hydrocarbons 1041
- 24.4** Chemistry of the Functional Groups 1044

*CHEMISTRY in Action*

The Petroleum Industry 1050

*Summary of Facts & Concepts* 1052

*Key Words* 1053

*Questions & Problems* 1053

*CHEMICAL Mystery*

The Disappearing Fingerprints 1058



## Synthetic and Natural Organic Polymers 1060

**25.1** Properties of Polymers 1061

**25.2** Synthetic Organic Polymers 1061

**25.3** Proteins 1067

*CHEMISTRY in Action*

Sickle Cell Anemia—A Molecular Disease 1074

**25.4** Nucleic Acids 1075

*CHEMISTRY in Action*

DNA Fingerprinting 1078

*Summary of Facts & Concepts* 1079

*Key Words* 1079

*Questions & Problems* 1079

*CHEMICAL Mystery*

A Story That Will Curl Your Hair 1084

**Appendix 1** Derivation of the Names of Elements A-1

**Appendix 2** Units for the Gas Constant A-7

**Appendix 3** Thermodynamic Data at 1 atm and 25°C A-8

**Appendix 4** Mathematical Operations A-13

*Glossary* G-1

*Answers to Even-Numbered Problems* AP-1

*Credits* C-1

*Index* I-1

**A**

Absolute entropy, 784, 790  
 Absolute temperature scale, 15, 182  
 Absolute zero, 182  
 Absorption spectrum, 566, 1013  
 Acceptor impurity, 943  
 Accuracy, 22  
 Acetaldehyde ( $\text{CH}_3\text{CHO}$ ), 1046  
 Acetic acid ( $\text{CH}_3\text{COOH}$ ), 121, 669, 736, 1045  
     ionization constant of, 680  
     titrations of, 736  
 Acetic acid-sodium acetate system, 723, 727  
 Acetone ( $\text{CH}_3\text{COCH}_3$ ), 1046  
 Acetyl chloride ( $\text{CH}_3\text{COCl}$ ), 1047  
 Acetylene ( $\text{C}_2\text{H}_2$ ), 1039  
     bonding in, 381, 443  
     properties and reactions of, 1039  
 Acetylsalicylic acid (aspirin), 680, 709  
 Achiral molecules, 1009  
 Acid(s), 62, 126, 669  
     Arrhenius, 127  
     Brønsted, 127, 669  
     diprotic, 128, 690  
     general properties of, 127  
     ionization constants of. See Ionization constants  
         Lewis, 706  
         monoprotic, 128, 679  
         polyprotic, 128, 690  
         strength of, 675, 694  
         strong and weak, defined, 675  
         triprotic, 128, 694  
 Acid ionization constants ( $K_a$ ), 680  
     of diprotic and polyprotic acids, 692  
     of monoprotic acids, 680  
     relation between base ionization constants and, 689  
 Acid paper, 720  
 Acid rain, 704, 918  
 Acid strength, 675, 694  
 Acid-base indicators, 152, 741, 743 (table)  
 Acid-base properties, 127  
     of hydroxides, 705  
     of oxides, 704  
     of salt solutions, 698  
     of water, 670  
 Acid-base reactions, 130, 151, 732  
 Acid-base theory  
     Arrhenius, 127  
     Brønsted, 127  
     Lewis, 706  
 Acid-base titrations, 151, 732  
 Acidic oxides, 359, 704

Actinide series, 313  
 Activated complex, 591  
 Activation energy ( $E_a$ ), 591, 1017  
 Active site, 607  
 Active transport, 708  
 Activity, 629, 673  
 Activity series, 140  
 Actual yield, 103  
 Addition reactions, 606, 1037, 1061  
 Adenine, 804, 1075  
 Adenosine diphosphate, 804  
 Adenosine triphosphate, 804  
 Adhesion, 475  
 Adiabatic process, 240  
 Adipic acid, 1065  
 Aerosols, 549, 912, 923  
 AIDS, 457  
 Air, composition of, 903  
 Air pollution  
     carbon monoxide and, 926  
     radon and, 923  
     smog and, 921  
     sulfur dioxide and, 919  
 Alcohol(s), 1044  
     condensation reactions of, 1045  
     denatured, 1045  
     oxidation of, 1044  
 Alcohol dehydrogenase, 608, 1044  
 Aldehydes, 1046  
 Aliphatic alcohols, 1044  
 Aliphatic hydrocarbons.  
     See Alkanes  
 Alkali metal(s), 50, 351, 944  
     coinage metals compared with, 358  
     electronegativity, 944  
     group trends of, 351  
     ionization energy, 944  
     properties of, 351, 944  
     reactions of, with oxygen, 351, 945  
 Alkali metal hydroxides, 676, 947  
 Alkaline earth metal(s), 50, 352, 948  
     properties of, 352, 948  
 Alkaline earth metal  
     hydroxides, 676  
     amphotерism of, 705  
 Alkanes (aliphatic hydrocarbons), 65, 1029  
     nomenclature of, 1030  
     optical isomerism of  
         substituted, 1034  
     reactions of, 1033  
 Alkenes (olefins), 1035  
     geometric isomers of, 1037  
     nomenclature of, 1036  
     properties and reactions of, 1036  
 Alkyl group, 1031  
 Alkyl halides, 1034  
 Alkynes, 1039  
 Allotropes, 52, 254  
     carbon, 52, 254, 456, 965  
     oxygen, 52, 977  
     phosphorus, 972  
     sulfur, 981  
     tin, 494  
 Alloys, 934  
 Alpha helix, 1071  
 Alpha ( $\alpha$ ) particles, 43  
 Alpha ( $\alpha$ ) rays. See Alpha particles  
 Alum, 953  
 Aluminum, 353, 950  
     metallurgy of, 950  
     recovery of, 952  
 Aluminum chloride ( $\text{AlCl}_3$ ), 701, 951  
 Aluminum hydride ( $\text{AlH}_3$ ), 952, 961  
 Aluminum hydroxide [ $\text{Al}(\text{OH})_3$ ], 705, 952  
 Aluminum oxide ( $\text{Al}_2\text{O}_3$ ), 353, 950  
 Aluminum sulfate [ $\text{Al}_2(\text{SO}_4)_3$ ], 720  
 Amalgams, 848, 934  
 Amide group, 1070  
 Amide ion, 677, 970  
 Amines, 1048  
 Amino acids, 1067, 1068 (table)  
 Aminobenzene (aniline), 1048  
 Ammonia ( $\text{NH}_3$ ), 970  
     as base, 129  
     in fertilizers, 105  
     ionization constant of, 687  
     ion product, 970  
     as Lewis base, 706  
     molecular geometry, 420, 435  
     preparation of, 603, 654  
     solubility of, 532  
     as solvent, 946  
 Ammonium chloride ( $\text{NH}_4\text{Cl}$ ), 700  
 Ammonium ion, 56, 129  
 Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ), 105, 976  
 Amorphous solids, 494  
 Ampere (A), 847  
 Amphibolic hydroxide, 705, 763  
 Amphibolic oxides, 359, 704  
 Amplitude of wave, 277  
 Anaerobic organism, 1029  
 Analytical chemistry. See Chemical analysis  
 Angstrom ( $\text{\AA}$ ), 44  
 Angular momentum quantum number ( $l$ ), 298  
 Anhydrous compounds, 64  
 Aniline (aminobenzene), 1048  
 Anions, 51  
     containing metal atoms, 1006  
     electron configuration of, 335  
 hydrolysis, 699  
 names of, 58, 1006  
 radius of, 339  
 Anode, 41, 818  
     sacrificial, 843  
 Antacids, 708  
 Antibonding molecular orbitals, 446  
 Antifreeze, 540  
 Antiknocking agent, 1051  
 Antitumor agents, 1020  
*Aqua regia*, 972  
 Aqueous solution, 119  
 Aqua ligand, 1006  
 Argon, 357, 360  
 Aristotle, 39  
 Aromatic hydrocarbons: 1041  
     nomenclature of, 1041  
     properties and reactions of, 1042  
 Arrhenius, Svante, 127  
 Arrhenius acid-base theory, 127  
 Arrhenius equation, 591  
 Arsenic, 170, 1085  
 Art forgery, 900  
 Artificial radioactivity, 876  
 Artificial snow, 240  
 Ascorbic acid. See Vitamin C  
 Aspirin (acetylsalicylic acid), 680, 709  
 Astatine, 356  
 Aston, Francis, 84  
 Atactic polymers, 1062  
 Atmospheric composition, 903  
 Atmospheric pollution. See air pollution  
 Atmospheric pressure, 175  
     boiling point and, 506  
     freezing point and, 506  
     standard, 176  
 Atom, 40  
     Dalton's theory of, 39  
     emission spectrum of, 284  
     Greek theories of, 39  
     Rutherford's model of, 44  
     structure of, 45  
     Thomson's model of, 43  
 Atomic bomb, 47, 881  
 Atomic mass, 76  
 Atomic mass unit (amu), 76  
 Atomic nucleus, 44  
 Atomic number ( $Z$ ), 46, 330  
 Atomic orbitals, 297, 299  
     electron assignment to, 308  
     energies of, 302  
     hybrid. See Hybrid orbitals  
     relationship between quantum numbers and, 297  
 Atomic radii, 337  
 Atomic theory. See Atom

Atomic weight. *See* Atomic mass  
Aufbau principle, 310  
Aurora borealis, 906  
Autumnization of water, 670  
Automotive emissions, 604, 921  
Average atomic mass, 76  
Average bond enthalpies, 401  
Avogadro, Amedeo, 78, 183  
Avogadro's law, 183  
Avogadro's number, 78  
Axial position, 418

**B**

Bacteria fuel cell, 839  
Balancing equations, 92, 815  
equilibrium constant and, 637  
nuclear reactions, 865  
redox reactions, 815  
Ball-and-stick model, 52  
Balmer series, 287  
Band theory, 941  
Barium, 352, 949  
Barium hydroxide  $[Ba(OH)_2]$ , 129, 676  
Barium sulfate  $(BaSO_4)$ , 744  
Barometer, 176  
Bartlett, Neil, 357  
Base(s), 64, 127, 669  
Arrhenius, 127  
Bronsted, 127, 669  
general properties of, 127  
ionization constant of, 687  
Lewis, 706  
strength of, 676  
Base ionization constants ( $K_b$ ), 687  
relationship between acid ionization constants and, 689

Base pairs, 1076  
Base strength, 676  
Basic oxides, 359, 704  
Basic oxygen process, 937  
Batteries, 834  
dry cell, 834  
fuel cell, 837  
lead storage, 835  
mercury, 834  
lithium ion, 836

Bauxite, 950  
Becquerel, Antoine, 43  
Belt of stability, 868  
Benzene ( $C_6H_6$ ), 1041  
bonding in, 392, 454  
electron micrograph of, 1041  
structure of, 392, 454, 1041

Benzoic acid, 698, 1047

Beryl, 933

Beryllium, 352, 948

Beryllium chloride ( $BeCl_2$ ), 417, 435

Beryllium hydride ( $BeH_2$ ), 394, 961

Beta ( $\beta$ ) particles, 43

Beta pleated sheet, 1071

Beta ( $\beta$ ) rays. *See* Beta particles

Bidentate ligands, 1003

Big Bang theory, 6

Bimolecular reaction, 596

Binary compounds, 56

Binary hydrides, 960

Binding energy. *See* Nuclear binding energy  
Biological effects of radiation, 890  
Biological nitrogen fixation, 903  
Biosphere II, 228  
Blast furnace, 936  
Blood  
oxygen in, 533, 653, 734  
pH of, 734  
Body-centered cubic cell (bcc), 481  
Bohr, Niels, 284  
Bohr model, 284  
Boiler scale, 126  
Boiling point, 500  
and intermolecular forces, 500  
pressure and, 500, 506  
vapor pressure and, 500  
Boiling-point elevation, 538  
Boltzmann, Ludwig, 202  
Boltzman constant, 782  
Boltzmann equation, 782  
Bomb calorimeter, 248  
Bombardier beetle, 257  
Bond(s)  
coordinate covalent, 395  
of coordination compounds, 1011  
covalent. *See* Covalent bonds  
dative, 395  
double. *See* Double bonds  
electronegativity and, 382  
enthalpy, 400  
hydrogen. *See* Hydrogen bond  
ionic, 372, 374  
length, 381  
in metals, 493, 941  
multiple, 380  
pi, 442  
polar covalent, 382  
sigma, 442  
single. *See* Single bonds  
in solids, 488  
triple. *See* Triple bonds  
Bond angles, 416, 420  
Bond enthalpy, 400, 401 (table)  
Bond length, 381  
Bond moments, dipole, 425  
Bond order, 449  
Bond polarity, 382  
Bond strength, acid strength and, 695  
Bonding molecular orbitals, 446  
Bonding pairs, 415, 419  
Boric (orthoboric) acid, 707  
Born, Max, 375  
Born-Haber cycle, 374  
Boron, 353  
Boron neutron capture therapy, 893  
Boron trifluoride ( $BF_3$ ), 394,  
436, 706  
Bose, Satyendra, 208  
Bose-Einstein condensate, 208  
Boundary surface diagrams, 300  
Boyle, Robert, 178  
Boyle's law, 178  
Bragg, Sir William L., 487  
Bragg, William H., 487  
Bragg equation, 486  
Brass, 521  
Breathalyzer, 144  
Breeder reactors, 883

Bromine, 142, 356, 984, 990  
Bromine-formic acid reaction, 566  
Brønsted, Johannes N., 127  
Brønsted acid, 127, 669  
Brønsted base, 127, 669  
Brønsted acid-base theory, 127, 669  
Buckminsterfullerene.  
*See* Buckyball  
Buckyball, 456  
Buffer solutions, 726  
Buret, 12, 152  
Butadiene, 1065

**C**

Calcite. *See* Calcium carbonate  
Calcium, 352, 949  
Calcium carbide ( $CaC_2$ ), 966, 1039  
Calcium carbonate ( $CaCO_3$ ), 762,  
920, 949  
decomposition of, 632, 795  
production of iron, 936  
sulfur dioxide removal with, 920  
Calcium hydroxide [ $Ca(OH)_2$ :  
slaked lime], 949  
Calcium oxide ( $CaO$ : quicklime),  
372, 920, 949  
Calcium phosphate, 762, 975  
Calorie, 250  
Calorimeter  
constant-pressure, 251  
constant-volume bomb, 248  
Calorimetry, 246  
Cancer, 893, 1020. *See also*  
Carcinogenicity  
Capillary action, 475  
Carbides, 966, 1039  
Carbon, 354, 965  
allotropes of, 52, 254, 456,  
965. *See also* Diamond;  
Graphite  
atomic mass of, 76  
in inorganic compounds, 56  
phase diagram of, 965  
in steelmaking, 938  
Carbon cycle, 914  
Carbon dioxide ( $CO_2$ ), 967  
acidic properties, 705  
bond moments of, 426  
climate and, 914  
enthalpy of formation of, 256  
indoor pollutant, 926  
phase diagram of, 506  
photosynthesis and, 601, 915  
solid (dry ice), 506  
solubility of, 533  
toxicity of, 533  
Carbon disulfide ( $CS_2$ ), 983  
Carbon-12, 76  
Carbon-14, 588, 875  
Carbon-14 dating, 588, 875  
Carbon monoxide ( $CO$ ), 967  
enthalpy of formation, 258  
from automotive emissions,  
605, 921  
hemoglobin affinity for, 926  
indoor pollutant, 926  
metal purification with, 939  
toxicity of, 926

Carbon tetrachloride ( $CCl_4$ ),  
381, 1034  
Carbonate ion, 388, 392, 455  
Carbonic acid ( $H_2CO_3$ ), 636,  
690, 707  
formation, 707, 734  
ionization constants, 692  
Carbonic anhydride, 734, 762  
Carbonyl group, 1046  
Carborundum, 966  
Carboxyhemoglobin, 926  
Carboxyl group, 1046  
Carboxylic acids, 1046  
acid strength, 697  
Carcinogenicity  
of amines, 1048  
of ethylene dibromide, 990  
of polycyclic aromatic  
hydrocarbons, 1043  
of radiation, 891  
Carothers, Wallace, 1065  
Cast (pig) iron, 937  
Catalysis, 601  
air pollution reduction by, 604  
enzyme, 606  
heterogeneous, 603  
homogeneous, 605  
Catalysts, 601  
in catalytic converters, 604  
effects of, on equilibrium, 652  
enzymes as, 606  
heterogeneous, 603  
homogeneous, 605  
Natta-Ziegler, 1063  
Catalytic converters, 604  
Catalytic rate constant ( $k_c$ ), 602  
Catenation, 965, 1028  
Cathode, 41, 818  
Cathode ray(s), 41  
Cathode ray tube, 41  
Cathodic protection, 842  
Cations, 51  
electron configuration of, 334  
hydrolysis of, 700  
identification of, 763  
ionic radius of, 339  
nomenclature of, 58  
Caustic soda. *See* Sodium  
hydroxide  
Cell diagram, 819  
Cell potential, 819  
Cell voltage, 819. *See also*  
Electromotive force  
Cellulose, 720  
Celsius temperature scale, 15  
Cementite, 938  
Cesium, 351  
Chadwick, James, 45  
Chain reaction, nuclear, 880  
Chalcopyrite ( $CuFeS_2$ ), 1001  
Chalk, 949  
Chargaff, E., 1075  
Chargaff's rule, 1075  
Charge cloud (electron charge  
cloud), 297  
Charge-to-mass ratio ( $e/m$ ), 41  
Charles, Jacques, 181  
Charles's law (Charles's and  
Gay-Lussac's law), 182

- Chelating agents, 1004  
 Chemical analysis.  
*See also* Qualitative analysis;  
 Quantitative analysis  
 with coordination  
 compounds, 1020  
 Chemical energy, 231  
 Chemical equations, 90  
     balanced. *See* Balancing  
     equations  
     free elements in, 334  
     interpretation of, 91  
 Chemical equilibrium, 121, 624  
 Chemical formulas, 52  
     empirical, 53, 88  
     molecular, 52  
     structural, 53  
 Chemical kinetics, 565  
 Chemical properties, 11  
 Chemical reactions, 90  
     acid-base, 130, 151, 732  
     addition, 606, 1037, 1061  
     of alkanes, 1033  
     of alkenes, 1036  
     of alkynes, 1039  
     of aromatic compounds, 1042  
     bimolecular, 596  
     combination, 137  
     combustion, 139  
     condensation, 1045, 1065, 1067  
     of coordination compounds, 1017  
     Dalton's definition of, 39  
     decomposition, 139  
     displacement, 139  
     disproportionation, 142  
     first-order, 577  
     gases in, 193  
     half, 133  
     half-cell, 818  
     metathesis, 121  
     neutralization, 130, 151, 732  
     nuclear reactions compared  
         with, 865  
     oxidation-reduction. *See*  
         Oxidation-reduction  
         reactions  
     precipitation, 121, 750  
     rate of. *See* Rate of reaction  
     second-order, 584  
     spontaneous, 779, 785, 791  
     substitution, 1042  
     termolecular, 596  
     thermite, 951  
     unimolecular, 596  
     zero-order, 587, 609  
 Chemistry, 2  
 Chernobyl, 885  
 Chile saltpeter ( $\text{NaNO}_3$ ), 947  
 Chiral molecules, 1009, 1034  
 Chlor-alkali process, 986  
 Chlorine, 356, 984  
     preparation of, 986  
     uses of, 989  
 Chlorine monoxide ( $\text{ClO}$ ), 909  
 Chlorofluorohydrocarbons  
     (CFCs), 909  
 Chloroform ( $\text{CHCl}_3$ ), 1034  
 Chlorophyll, 1019  
 Chlorous acid ( $\text{HClO}_2$ ), 63, 989  
 Cholesterol, 1049  
 Chromium, 312, 998  
 Chromosomes, 891  
 Cinnamic aldehyde, 1046  
 Cisplatin, 1020  
 Cis-trans isomers  
     of alkenes, 1036  
     of coordination compounds, 1008  
 Clapeyron, Benoit, 498  
 Clausius, Rudolf, 498  
 Clausius-Clapeyron equation, 498  
 Climate  
     carbon dioxide and, 914  
     effects of water on, 477  
 Closed system, 232  
 Closest packing, 482  
 Cloud seeding, 990  
 Coal, 965  
 Coal gasification, 968  
 Cohesion, 475  
 Coinage metals, 358  
 Coke, 936  
 Colligative properties  
     of electrolyte solutions, 546  
     of nonelectrolyte  
         solutions, 534  
 Collision theory, 590  
 Colloids, 548  
 Color  
     of glass, 495  
     of indicators, 743  
     of transition metal ions, 1012  
     wavelength and, 280, 1012  
 Color wheel, 1012  
 Combination reaction, 137  
 Combustion, 139  
     of acetylene, 258, 1039  
     of alkanes, 1033  
     of hydrogen, 11, 232  
     of methane, 243, 1033  
     of sulfur, 137, 235  
 Common ion effect  
     acid-base equilibria and, 723  
     solubility and, 753  
 Complex ion(s), 758, 1002  
     magnetic properties of, 1014  
     solubility equilibria and, 758  
     *See also* Coordination  
         compounds  
 Complex ion formation, 758  
 Compounds, 8  
     anhydrous, 64  
     aromatic. *See* Aromatic  
         hydrocarbons  
     coordination. *See* Coordination  
         compounds  
     in Dalton's theory, 39  
     inorganic, 56  
     ionic, 51, 54, 374  
     molecular, 59  
     nonstoichiometric, 962  
     organic, 56, 65, 1028  
 Concentration, 145, 524  
     chemical equilibria and  
         changes in, 647  
     effects on emf, 829  
 Concentration cells, 833  
 Concentration of solution,  
     145, 524  
 Concentration units, 145, 524  
     compared, 526  
     molality, 525  
     molarity, 145, 525  
     mole fraction, 197, 525  
     percent by mass, 524  
 Condensation, 497  
 Condensation reactions, 1045,  
     1065, 1067  
 Conduction band, 941  
 Conductivity  
     of metals, 493, 941  
     of nonmetallic elements, 942  
 Conductor, 942  
 Conjugate acid, 669  
 Conjugate acid-base pair, 669, 689  
 Conjugate base, 669  
 Constant-pressure calorimeter, 251  
 Constant-volume bomb  
     calorimeter, 248  
 Constructive interference, 446, 487  
 Contact process, 983  
 Control rods, 882  
 Cooling curve, 503  
 Cooperativity, 1072  
 Coordinate covalent bonds, 395, 706  
 Coordination compounds, 1002  
     applications of, 1018  
     bonding in, 1011  
     in living systems, 1018  
     magnetic properties, 1014  
     naming, 1005  
     oxidation number, 1004  
     reactions of, 1017  
     stereochemistry of, 1008  
 Coordination number, 481, 1003  
 Coordination theory of Werner, 1002  
 Copolymer, 1065  
 Copper, 1001  
     corrosion of, 842  
     electron configuration of, 312  
     ionization energy of, 358  
     metallurgy of, 1001  
     purification of, 939  
 Copper carbonate ( $\text{CuCO}_3$ ;  
     patina), 842  
 Copper sulfate ( $\text{CuSO}_4$ ), 64  
 Core  
     atomic. *See* Nucleus  
     noble gas, 310  
     nuclear reactor, 882  
 Core electrons, 332  
 Corona, 326  
 Corrosion, 840  
 Corundum ( $\text{Al}_2\text{O}_3$ ), 950  
 Coulomb (C), 826, 847  
 Coulomb, Charles, 374  
 Coulomb's law, 374, 867  
 Coupled reactions, 802  
 Covalent bonds, 379  
     coordinate, 395  
     polar, 382  
 Covalent compounds, 379  
 Covalent crystals, 492  
 Covalent hydrides, 961  
 Cracking process, 1037  
 Crenation, 543  
 Crick, Francis, 1076  
 Critical mass, 880  
 Critical pressure ( $P_c$ ), 501  
 Critical temperature ( $T_c$ ), 501,  
     502 (table)  
 Crown ether, 932, 946  
 Crude oil, 1050  
 Cryolite ( $\text{Na}_3\text{AlF}_6$ ), 950  
 Crystal(s), 488, 493 (table)  
     covalent, 492  
     ionic, 488  
     metallic, 493  
     molecular, 492  
     X-ray diffraction by, 486  
 Crystal field splitting, 1012  
 Crystal field theory, 1011  
 Crystal structure, 478  
 Crystalline solids, 478  
 Crystallization, 521  
     fractional, 529  
 Cubic close-packed (ccp)  
     structure, 483  
 Cubic unit cell, 480  
 Curie (Ci), 890  
 Curie, Marie, 43  
 Curie, Pierre, 43  
 Cyanide, 966  
 Cycloalkanes, 1035  
 Cyclohexane, 1035  
 Cyclotron, 877  
 Cytochrome c, 1019  
 Cytochrome oxidase, 966  
 Cytosine, 1075

**D**

- d* Orbitals, 301, 1011  
     and crystal field theory, 1011  
     hybridization of, 441  
 Dacron, 1065  
 Dalton (atomic mass unit), 76  
 Dalton, John, 39  
 Dalton's atomic theory, 39  
 Dalton's law of partial  
     pressures, 196  
 Daniel cell, 818  
 Data, 4  
 Dating, radionuclear, 588, 875  
 Dative bonds, 395  
 Davission, Clinton, 293  
 de Broglie, Louis, 289  
 de Broglie's hypothesis, 289  
 Debye (D), 426  
 Debye, Peter J., 426  
 Decay series. *See* Radioactive  
     decay series  
 Decomposition reactions, 139  
 Definite proportions, law of, 40  
 Delocalized molecular orbitals, 454  
     of benzene, 454  
     of carbonate ion, 455  
     of metals, 493, 941  
 Democritus, 39  
 Denaturant, 1075  
 Denatured alcohol, 1045  
 Denatured proteins, 776, 1075  
 Denitrification, 904  
 Density, 11  
     gas, 190  
     of nucleus, 867  
     water, 478

**E**

- Earth  
age of, 876  
composition of, 49 (*table*)
- EDTA (ethylenediaminetetraacetate), 1003  
treatment of metal poisoning with, 1004
- Effective nuclear charge, 336
- Efficiency, 793
- Effusion, gaseous, 209
- Egg.  
formation, 762  
hard boiling, 507, 776
- Einstein, Albert, 40, 208, 281, 870
- Einstein's mass-energy equation, 870
- Einstein's relativity theory, 870, 877
- Elastomers (synthetic rubber), 1064
- Electrical work, 826
- Electrocatalysts, 838
- Electrochemical series, 140
- Electrochemistry, 815
- Electrode(s), 818  
anode, 818  
cathode, 818
- Electrode potential. *See* Standard reduction potential
- Electrolysis, 843  
of aqueous sodium chloride, 845  
metal purification by, 939  
of molten sodium chloride, 843  
quantitative aspects of, 847  
of water, 844
- Electrolyte(s), 119  
strong, 120  
weak, 120
- Electrolyte solutions, colligative properties of, 546
- Electrolytic cell, 843
- Electromagnetic radiation, 279
- Electromagnetic wave, 278
- Electromotive force (emf), 819  
effects of concentration on, 829  
standard, 821
- Electron(s), 41  
charge-to-mass ratio of, 41  
nonbonding. *See* Lone pairs  
probability distribution of, 300  
valence, 332
- Electron affinity ( $E_A$ ), 347, 348 (*table*)
- Electron capture, 869
- Electron charge, 41
- Electron charge cloud, 297
- Electron configuration, 304  
anions, 335  
Aufbau principle and, 310  
cations, 334  
diamagnetism and  
paramagnetism in, 305
- electron assignment to orbitals in, 304
- ground state, 304, 311  
Hund's rule and, 307  
and molecular orbitals, 448
- Pauli exclusion principle and, 305
- and shielding effect, 306
- Electron density, 297
- Electron microscope, 294
- Electron probability, 296, 300
- Electron spin, 298, 304  
in coordination compounds, 1014  
Hund's rule and, 307  
Pauli exclusion principle and, 305
- Electron spin quantum number ( $m_s$ ), 298
- Electron subshell, 298
- Electron-dot symbols, 371
- Electronegativity, 382
- Elementary particles, 865
- Elementary steps, 596
- Elements, 7  
abundance, 49  
atomic radii of, 337  
classification of, 48, 331  
derivation of names and symbols, A-1  
electron affinity of, 347  
electronegativity of, 382  
essential, 49  
ground state electron configurations of, 311 (*table*), 331
- ionization energies of, 344 (*table*)  
periodic and group properties of, 349
- representative, 332  
symbols of, 8 (*table*)
- transuranium. *See* Transuranium elements
- Emf. *See* Electromotive force
- Emission spectra, 284
- Empirical formula, 53, 88
- Emulsion, 549
- Enantiomers, 1009
- End point, 741
- Endothermic process, 233
- Energy, 231  
chemical, 231  
crystal field splitting, 1012  
of hydrogen atom, 286  
ionization, 342  
kinetic. *See* Kinetic energy
- nuclear binding. *See* Nuclear binding energy  
potential. *See* Potential energy
- solar. *See* Solar radiation
- thermal. *See* Heat  
unit of, 202
- Energy changes  
in chemical reactions, 242  
and first law of thermodynamics, 234
- Enthalpy ( $H$ ), 241  
and Born-Haber cycle, 374  
standard, 254
- Enthalpy of reaction, 242
- Enthalpy of solution, 260
- Entropy ( $S$ ), 780  
absolute, 784, 790  
changes, 782
- and microstate, 781  
phase transition, 782, 797  
standard, 784
- Environmental pollution  
acid rain, 704, 918  
Freon, 909  
nuclear wastes, 885  
sulfur dioxide, 919  
thermal, 530, 882
- Enzyme(s), 606  
alcohol dehydrogenase, 608, 1044  
carbonic anhydrase, 734, 762  
catalysis of, 606  
cytochrome oxidase, 966  
hexokinase, 607  
HIV-protease, 457  
lock-and-key model of, 607
- Enzyme-substrate intermediate (ES), 608
- Equation  
Arrhenius, 591  
Boltzmann, 782  
chemical, 90  
Clausius-Clapeyron, 498  
Einstein, 870  
Henderson-Hasselbach, 724  
ideal gas, 184  
ionic, 124  
molecular, 123  
Nernst, 830  
net ionic, 124  
nuclear, 865  
redox, 815  
Schrödinger, 296  
thermochemical, 243  
van der Waals, 212
- Equatorial position, 418
- Equilibrium, 121, 624  
catalyst effect on, 652  
and chemical kinetics, 639  
and concentration changes, 647  
dynamic, 497  
free energy and, 798  
heterogeneous, 632  
homogeneous, 627  
liquid-solid, 501  
liquid-vapor, 496  
multiple, 635  
solid-vapor, 504  
and temperature changes, 650  
volume and pressure changes and, 648
- Equilibrium constant ( $K$ ), 626, 799  
balanced equation and, 637  
and equilibrium concentration calculations, 643  
in heterogeneous equilibrium, 633  
in homogeneous equilibrium, 627  
and law of mass action, 626  
in multiple equilibria, 635  
units, 629
- Equilibrium vapor pressure, 497
- Equivalence point  
in acid-base titrations, 152, 732  
in redox titrations, 155
- Erythrocytes. *See* red blood cells
- Escape velocity, 207
- Essential elements, 49
- Esters, 1047

- Ethane ( $C_2H_6$ ), 1029  
 Ethanol ( $C_2H_5OH$ ), 88, 1044  
 Ethers, 1045  
 Ethyl acetate ( $CH_3COOC_2H_5$ ),  
     605, 1048  
 Ethyl group ( $C_2H_5$ ), 1031  
 Ethylene ( $C_2H_4$ ), 1035  
     bonding in, 381, 442  
     in polymerization, 1062  
 Ethylene dibromide, 990  
 Ethylene glycol [ $CH_2(OH)CH_2(OH)$ ],  
     540, 1045  
 Ethylenediamine, 1003  
 Ethylenediaminetetraacetate,  
     *See* EDTA  
 Eutrophication, 1022  
 Evaporation. *See* Vaporization  
 Excess reagent, 99  
 Excited level (excited state), 286  
 Exothermic processes, 233  
 Expanded octet, 395  
 Expanded valence shell, 395, 441  
 Explosives, 881, 948, 976  
 Exponential notation. *See*  
     Scientific notation  
 Extensive properties, 11
- F**
- /Orbitals, 301, 312
  - Face-centered cubic unit cell (fcc),  
     481, 483
  - Factor label method, 23
  - Fahrenheit temperature scale.  
     *See* Temperature scale
  - Family of elements, 48
  - Faraday, Michael, 826, 1041
  - Faraday constant ( $F$ ), 826
  - Fat cells, 250
  - Fermentation, 915, 1044
  - Ferromagnetic substances, 934
  - Fertilizers, 105
  - Fingerprints, 1058
  - First law of thermodynamics, 234
  - First-order reactions, 577
  - Fischer, Emil, 607
  - Fission reactions, 879
  - Fission reactors, 881
  - Flame test, 764
  - Flotation method, 934
  - Fluorapatite, 105
  - Fluoridation, 989
  - Fluorine, 356, 984  
     fluoridation with, 989  
     mass defect of, 870  
     oxidation number of, 136, 385  
     preparation of, 985  
     uses, 989
  - Fluorite ( $CaF_2$ ), 489, 949
  - Flux, 936
  - Food irradiation, 892
  - Force, 175  
     adhesive, 475  
     dispersion, 471  
     intermolecular. *See*  
         Intermolecular forces  
     intramolecular, 469  
     unit of, 175  
     van der Waals, 469
  - Formal charge, 389  
 Formaldehyde ( $CH_2O$ ), 444,  
     926, 1046
  - Formation constant ( $K_f$ ), 758,  
     759 (*table*)
  - Formic acid ( $HCOOH$ ), 566,  
     680, 1047
  - Formula mass, 83
  - Formulas. *See* Chemical formulas
  - Fossil fuels, 964, 968, 1050
  - Fractional crystallization, 529
  - Fractional distillation, 537, 1050
  - Fractional precipitation, 751
  - Fractionating column, 537, 1050
  - Francium, 343
  - Frasch, Herman, 980
  - Frasch process, 980
  - Fraunhofer, Josef, 326
  - Free energy ( $G$ ), 791  
     chemical equilibria and, 798  
     and electrical work, 826  
     in phase transition, 797  
     spontaneity and, 792  
     standard free energy of  
         reaction, 792  
     temperature and, 795
  - Free radicals, 891, 1034
  - Freezing point, 501
  - Freezing-point depression, 539
  - Freons, 909, 988
  - Frequency ( $\nu$ ), 277
  - Frequency factor ( $A$ ), 592
  - Fuel, fossil. *See* Fossil fuels
  - Fuel cell, 837
  - Fuel value, 250
  - Functional groups, 65, 1028,  
     1049 (*table*)
  - Fusion  
     entropy and, 797  
     molar heat of, 503 (*table*)  
     nuclear, 885
  - Gallium, 329
  - Galvanic cells, 818
  - Galvanized iron, 842
  - Gamma ( $\gamma$ ) rays, 43
  - Gamow, George, 6
  - Gangue, 934
  - Gas(es), 9, 173  
     Avogadro's law, 183  
     Boyle's law, 178  
     Charles's law, 182  
     in chemical reactions, 193  
     Dalton's law of partial pressure  
         of, 196  
     density of, 190  
     diffusion of. *See* Diffusion  
     effusion of. *See* Effusion  
     emission spectrum of, 284  
     kinetic molecular theory of, 202  
     monatomic, 173  
     noble. *See* Noble gases  
     pressure of, 174  
     solubility of, 530, 531, 533
  - Gas constant ( $R$ ), 184  
     units of, 185, A-7  
     van der Waals, 212 (*table*)
  - Gasoline, 1051  
     antiknocking agents in, 1051
  - Gastric juice, 708
  - Gauge pressure, 274
  - Gay-Lussac, Joseph, 181
  - Geiger, Hans, 44
  - Geiger counter, 890
  - Genetic effects of radiation, 891
  - Geobacter, 839
  - Geometric isomer(s), 1008, 1037
  - Geometric shapes of orbitals,  
     299, 438
  - Gerlach, Walther, 299
  - Germer, Lester, 293
  - Gibbs, Josiah, 791
  - Gibbs free energy. *See* Free energy
  - Glass, 494, 495 (*table*)
  - Glass electrode, 832
  - Glucose ( $C_6H_{12}O_6$ ), 720, 1042
  - Glutamic acid, 1068, 1074
  - Glycerol, 476
  - Glycine, 1068, 1070
  - Gold  
     extraction of, 967  
     ionization energy of, 358  
     oxidation of, 972
  - Goodyear, Charles, 1064
  - Gram (g), 13
  - Graham, Thomas, 209
  - Graham's law of diffusion, 209
  - Graphene, 457
  - Graphite, 52, 254, 492, 965  
     as covalent crystal, 492  
     entropy of, 784
  - Gravimetric analysis, 149
  - Greenhouse effect, 914
  - Ground state (ground level), 286
  - Group (periodic), 48
  - Guanine, 1075
  - Guldberg, Cato, 626
  - Gunpowder, 948
  - Gypsum ( $CaSO_4 \cdot 2H_2O$ ), 949, 980
- H**
- $H_2$ . *See also* Hydrogen:  
     Hydrogen atom  
     Lewis structure of, 379  
     molecular orbitals of, 447  
     potential energy of, 431
  - Haber, Fritz, 375, 603
  - Haber process, 603, 654
  - Hair, 1084
  - Half-cell potential. *See* Standard  
     reduction potential
  - Half-cell reactions, 818
  - Half-life, 343, 582  
     of carbon-14, 588  
     of cobalt-60, 583, 887  
     of first-order reactions, 582  
     of francium-223, 343  
     of iodine-125, 889  
     of iodine-131, 889  
     of plutonium-239, 883  
     of potassium-40, 876  
     of radon-222, 924  
     of second-order reactions, 586  
     of sodium-24, 583, 888  
     of technetium-99, 889
  - Hemolysis, 542
  - Henderson-Hasselbach equation, 724
  - Henry, William, 531
  - Henry's law, 531, 533
  - Hertz (Hz), 278
  - Hess, German H., 256
  - Hess's law, 256, 262, 376
  - Heterogeneous catalysis, 603
  - Heterogeneous equilibria, 632
  - Heterogeneous mixture, 7
  - Heteronuclear diatomic  
     molecules, 916
  - of tritium, 877, 887, 962
  - of uranium-238, 875
  - of zero-order reactions, 587
  - Half-reaction, 133
  - Halic acids, 695, 988
  - Halides, 357, 987  
     alkali metal, lattice energy  
         and, 377  
     alkyl, 1034  
     hydrogen. *See* Hydrogen halides  
     phosphorus, 974  
     solubility of, 122
  - Hall, Charles, 950
  - Hall process, 950
  - Halogen(s), 50, 356, 984  
     displacement of, 141  
     electronegativity, 984  
     industrial and biological  
         roles of, 989  
     ionization energy, 984  
     oxoacids, 62, 988  
     preparation of, 985  
     properties of, 985
  - Halogenation of alkanes, 1033
  - Hard water, 126
  - Heat, 232, 239  
     of dilution, 262  
     of fusion, 502  
     of hydration, 262  
     of solution, 260  
     of vaporization, 497
  - Heat capacity ( $C$ ), 247
  - Heat content. *See* Enthalpy
  - Heat engine, 792
  - Heating curve, 503
  - Heavy water. *See* Deuterium oxide
  - Heavy water reactor, 882
  - Heisenberg, Werner, 295
  - Heisenberg uncertainty principle, 295
  - Helium, 357  
     boiling point of, 471  
     discovery of, 326  
     escape velocity of, 207  
     formation of, 873  
     intermolecular forces in, 471  
     ionization energy of, 344  
     primordial, 6
  - Hematite ( $Fe_2O_3$ ), 1000
  - Heme group, 1018, 1072
  - Hemodialysis, 548
  - Hemoglobin (Hb)  
     binding of oxygen, 533, 653,  
     1018, 1072  
     as buffer, 734  
     carbon monoxide affinity for, 926  
     production of, 653  
     structure of, 1018, 1073
  - Hemolysis, 542
  - Henderson-Hasselbach equation, 724
  - Henry, William, 531
  - Henry's law, 531, 533
  - Hertz (Hz), 278
  - Hess, German H., 256
  - Hess's law, 256, 262, 376
  - Heterogeneous catalysis, 603
  - Heterogeneous equilibria, 632
  - Heterogeneous mixture, 7
  - Heteronuclear diatomic  
     molecules, 916

- Hexagonal close-packed (hcp) structure, 483
- Hexamethylenediamine, 1065
- Hexokinase, 607
- High-spin complexes, 1014
- High-temperature superconductor, 409
- Hindenburg, 233
- Hiroshima, 881
- HIV, 457
- Homogeneous catalysis, 605
- Homogeneous equilibria, 627
- Homogeneous mixture, 7
- Homonuclear diatomic molecules, 450, 916
- Homopolymers, 1062
- Human immunodeficiency virus. *See* HIV
- Hund, Fredrick, 307
- Hund's rule, 307, 449, 452, 1014
- Hybrid orbitals, 433, 438 (*table*) of molecules with double and triple bonds, 442  
 $sp$ , 435, 443  
 $sp^2$ , 436, 442  
 $sp^3$ , 433  
 $sp^3d$ , 441  
 $sp^3d^2$ , 441
- Hybridization, 434
- Hydrate, 64, 1040
- Hydration, 120, 261 heat of, 262 of ions, 120, 261, 783 of protons, 128, 669
- Hydrazine ( $N_2H_4$ ), 970
- Hydrides binary, 960 covalent, 961 interstitial, 961 ionic, 961 phosphorus, 973
- Hydrocarbons, 65, 1028 aliphatic. *See* Alkanes alkynes. *See* Alkynes aromatic. *See* Aromatic hydrocarbons cycloalkanes, 1035 saturated, 1029 unsaturated, 1035, 1039, 1041
- Hydrochloric acid (HCl), 128, 695 in acid-base titrations, 732, 739 as monoprotic acid, 128 preparation of, 988
- Hydrocyanic acid (HCN), 680, 966
- Hydrofluoric acid (HF) ionization constant of, 680 as weak acid, 681
- Hydrogen, 350, 960 atomic orbitals of, 299 combustion of, 11, 232 displacement of, 139 isotopes of, 46, 962 metallic, 964 oxidation number of, 136 preparation of, 960 properties of, 350, 960
- Hydrogen atom Bohr's theory of, 284 emission spectrum of, 284
- energy of, 286 Schrödinger equation and, 296
- Hydrogen bomb, 887
- Hydrogen bond, 473, 1071, 1077
- Hydrogen bromide (HBr), 988
- Hydrogen chloride (HCl), 988
- Hydrogen cyanide (HCN), 174, 966
- Hydrogen economy, 964
- Hydrogen fluoride (HF), 382, 425, 988
- Hydrogen halides, 987 acid strength of, 695 dipole moments of, 427
- Hydrogen iodide (HI), 988 kinetics of formation, 598
- Hydrogen ion hydrated, 128, 669 pH and concentration, 673
- Hydrogen molecule ( $H_2$ ) combustion, 11, 232 Lewis structure, 379 molecular orbital, 447
- Hydrogen peroxide ( $H_2O_2$ ), 978 decomposition of, 143, 570, 598 disproportionation, 143 as oxidizing agent, 978 percent composition by mass of, 85 as reducing agent, 978
- Hydrogen sulfide ( $H_2S$ ), 981 as diprotic acid, 692 preparation of, 981 in qualitative analysis, 764
- Hydrogenation, 963
- Hydrogen-oxygen fuel cell, 837, 964
- Hydrohalic acids, 695, 988
- Hydrolysis alkaline (saponification; base hydrolysis), 1048 of anions, 699, 736 of esters, 601, 1048 metal ion, 701 salt, 698
- Hydrometer, 836
- Hydronium ion ( $H_3O^+$ ), 128, 669
- Hydrophilic interaction, 549
- Hydrophobic interaction, 549, 1074
- Hydroxides alkali metal, 676, 705, 947 alkaline earth metal, 676, 705 amphoteric, 705
- Hydroxyapatite, 744, 950
- Hydroxyl groups (OH groups), 1044
- Hydroxyl radical, 891, 912, 919
- Hypertonic solution, 542
- Hypochlorous acid, 63, 989
- Hypothesis, 4
- Hypotonic solution, 542
- I**
- Ice, 477
- ICE method, 643
- Ice skating, 507
- Ice-water equilibrium, 502
- Ideal gas, 185
- Ideal gas equation, 184
- Ideal solution, 536
- Impurities acceptor, 943 donor, 942
- Incomplete octet, 394
- Indicators. *See* acid-base indicators
- Induced dipole, 470
- Inert complexes, 1017
- Infrared active, 916
- Initial rate, 573
- Inorganic compounds, 56
- Instantaneous rate, 567
- Insulators, 942
- Intensive properties, 11
- Interference of waves, 446, 487
- Intermediates, 596
- Intermolecular forces, 174, 469 dipole-dipole forces, 469 dispersion forces, 470 ion-dipole forces, 470 ion-induced dipole, 470 van der Waals forces, 469
- Internal energy ( $U$ ), 235
- International System of Units (SI units), 12
- International Union of Pure and Applied Chemistry. *See* IUPAC
- Interstitial hydrides, 962
- Intramolecular forces, 469
- Iodine, 356, 984 nuclear stability of, 871 preparation of, 142, 987 sublimation of, 504 uses of, 990
- Iodine-131, 889
- Ion(s), 50 dipositive, 340 electron configuration of, 335 hydrated, 120, 261 hydrolysis, 698 monatomic, 51 polyatomic, 51 separation of, by fractional precipitation, 751 spectator, 124 transition metal, 57, 998, 1013 tripositive, 340 unipositive, 340
- Ion pairs, 546
- Ion product constant, 671
- Ion-dipole forces, 470
- Ion-electron method, 815
- Ion-induced dipole, 470
- Ionic bond, 372, 374, 384
- Ionic compounds, 51, 54 nomenclature, 56
- Ionic crystals, 488
- Ionic equation, 124
- Ionic hydrides, 961
- Ionic radii, 339
- Ionic solids (ionic crystals), 488
- Ionization constants of bases, 688 of diprotic and polyprotic acids, 692 of monoprotic acid, 680
- Ionization energy ( $IE$ ), 342, 344 (*table*)
- Ionizing radiation, 891
- J**
- Jeffreys, Alec, 1078
- Joule (J), 202
- Joule, James Prescott, 202
- Jupiter, 207, 964
- K**
- Kekule, August, 392, 1041
- Kelvin, Lord (William Thomson), 182
- Kelvin temperature scale, 15, 182
- Keratin, 1084
- Ketones, 1046
- Kilogram (kg), 13
- Kinetic energy, 202, 231
- Kinetic isotope effect, 963
- Kinetic molecular theory of gases, 202 liquids and solids in, 468
- Kinetics. *See* Chemical kinetics
- Krypton, 357
- L**
- Labile complexes, 1017
- Lachrymator, 922
- Lake Nyos, 533
- Lanthanide series. *See* Rare earth elements
- Laser, 290, 887
- Lattice energy ( $U$ ), 261, 374, 377 (*table*) of alkali metal halides, 377 and Born-Haber cycle, 374 and chemical formulas, 377
- Lattice point, 479
- Laue, Max von, 486
- Laughing gas (nitrous oxide), 65, 971
- Law, 4

- Law(s)**
- Avogadro's, 183
  - Boyle's, 178
  - Charles's, 181
  - of conservation of energy, 231
  - of conservation of mass, 40
  - Coulomb's, 374, 826
  - Dalton's, of partial pressures, 195
  - of definite proportions, 40
  - first law of thermodynamics, 235
  - Graham's, of diffusion, 209
  - Henry's, 531, 532
  - Hess's, 256, 258, 374
  - of mass action, 626
  - of multiple proportions, 40
  - of octaves, 329
  - Raoult's, 534
  - rate, 573
  - second law of thermodynamics, 785
  - third law of thermodynamics, 789
- Le Châtelier, Henry L.**, 646
- Le Châtelier's principle**, 646
- acid ionization and, 686, 742
  - chemical equilibrium and, 646
  - common ion effect and, 724, 753
  - and eggshell formation, 762
  - solubility equilibria and, 753
- Lead**, 354
- tetraethyl, 1052
  - tetramethyl, 1052
  - treatment of, 1004
- Lead**-206, 875, 900
- Lead chamber process**, 606
- Lead storage batteries**, 835
- Leclanché cell**, 834
- Length**, SI base unit of, 13
- Levotorsional isomers**, 1009
- Lewis acid**, 706
- Lewis base**, 706
- Lewis acid-base theory**, 706
- Lewis dot symbols**, 371
- Lewis, Gilbert N.**, 371
- Lewis structures**, 380
- formal charge and, 389
  - octet rule and, 380
  - and resonance concept, 392
- Libby, Willard F.**, 588
- Ligands**, 1002, 1003 (*table*)
- strong-field, 1014
  - weak-field, 1014
- Light**
- absorption of, and crystal field theory, 1012
  - electromagnetic theory of, 278
  - particle-wave duality of, 281, 289
  - plane-polarized, 1009
  - speed of, 279
- Light water reactors**, 881
- Lime**, 795, 921
- Limestone**. *See* Calcium carbonate
- Liming**, 921
- Limiting reagents**, 99
- Line spectra**, 284
- Linear molecule**, 417, 435
- Liquid(s)**, 10, 475
- properties of, 468 (*table*)
  - solutions of liquids in, 521
  - solutions of solids in, 521
- surface tension in, 475
- viscosity of, 476
- Liquid crystals**, 508
- Liquid-solid equilibrium**, 501
- Liquid-vapor equilibrium**, 496
- Liter (L)**, 14
- Lithium**, 351
- Lithium deuteride (LiD)**, 887
- Lithium fluoride (LiF)**, 374
- Lithium oxide (Li<sub>2</sub>O)**, 351
- Litmus**, 127
- Living systems**
- coordination compounds in, 1018
  - thermodynamics of, 802
- Lock-and-key theory**, 607
- Logarithm**, A-13
- London forces**. *See* Dispersion forces
- London, Fritz**, 471
- Lone pairs**, 380
- Low-spin complexes**, 1014
- Lucite (Plexiglas; polymethyl methacrylate)**, 1061
- M**
- Macromolecules**. *See* Polymers
- Macroscopic properties**, 12
- Magic number**, 867
- Magnesium**, 156, 353, 949
- band theory of, 941
  - cathodic protection with, 842
  - combustion, 133
  - preparation, 156
- Magnesium hydroxide [Mg(OH)<sub>2</sub>]**, 156, 709, 949
- Magnesium nitride (Mg<sub>3</sub>N<sub>2</sub>)**, 949
- Magnesium oxide (MgO)**, 133, 949
- Magnetic confinement**, 886
- Magnetic field**
- of electromagnetic waves, 279
  - electron spin and, 298, 305
- Magnetic quantum number (m<sub>l</sub>)**, 298
- Magnetism**, 305
- of complex ions, 1014
  - diamagnetism, 306, 1014
  - ferromagnetism, 934
  - paramagnetism, 306, 446, 1014
  - of transition metals, 1014
- Magnetite (Fe<sub>3</sub>O<sub>4</sub>)**, 1001
- Main group elements**, 332
- Manganese dioxide (MnO<sub>2</sub>)**, 198, 602
- Manganese nodules**, 934
- Manometer**, 177
- Many-electron atoms**, 297
- Marble**, 949
- Markovnikov, Vladimir**, 1037
- Markovnikov's rule**, 1037
- Marsden, Ernest**, 44
- Marsh, James**, 170
- Marsh gas**. *See* methane
- Marsh test**, 170
- Martian Climate Orbiter**, 17
- Mass**, 11
- atomic. *See* Atomic mass
  - critical, 880
  - defect, 870
  - electron, 46
  - formula, 83
- molar, 78, 191, 544
- molecular, 81
- number (A), 46
- percent composition by. *See* Percent composition
- SI base unit of, 13
- of subatomic particles, 46
- subcritical, 880
- Mass action**, law of, 626
- Mass defect**, 870
- Mass number (A)**, 46
- Mass spectrometer**, 84
- Mass-energy conversion**, 40, 870
- Matter**, 6
- classification of, 6
  - conservation of, 40
- Maxwell, James**, 203
- Maxwell speed distribution**, 204
- Mean square speed**, 206
- Mechanical work**, 237
- Melting**, entropy and, 797
- Melting point**, 501
- of alkali metal halides, 374
  - of alkali metals, 343
  - of diamond, 492
  - of francium, 343
  - pressure and, 506
  - of quartz, 492
- Membrane potential**, 833
- Mendeleev, Dmitri**, 329
- Mercury**
- in amalgam, 848, 934
  - in barometers, 176
  - mineral extraction with, 934
- Mercury batteries**, 834
- Mercury oxide (HgO)**, 139, 233, 780
- Mesosphere**, 906
- Metabolism**, 803
- Metal(s)**, 48, 493, 932
- alkali. *See* Alkali metal(s)
  - alkaline earth. *See* Alkaline earth metal(s)
  - bonding in, 493, 941
  - cottage, 358
  - displacement reactions, 140
  - corrosion. *See* Corrosion
  - in ionic compounds, 58
  - occurrence of, 934
  - preparation of, 935
  - properties of, 48, 943
  - purification of, 939
- Metal hydrides**, 961
- Metal ion**
- electron configurations, 334
  - hydrolysis of, 701
  - radii, 340
- Metallic bonds**, 493, 941
- Metallic crystals**, 493
- Metallic elements**, 48, 493, 932. *See also* Metal(s)
- Metalloids**, 48
- Metallurgy**, 934
- coordination compounds in, 939, 967
  - pyrometallurgy, 935
- Metathesis reaction**, 121
- Meter**, 13
- Methane (CH<sub>4</sub>)**, 1029
- combustion of, 243, 1033
  - hydrate, 1040
  - molecular geometry of, 418, 434
- Methane hydrate**, 1040
- Methanol (CH<sub>3</sub>OH)**, 423, 1044
- Methyl acetate**, 601
- Methyl chloride**, 1033
- Methyl group**, 1031
- Methyl radical**, 1034
- Methyl propyl ether (neophyl)**, 1046
- Methylene chloride**, 1033
- Methyl-tert-butyl ether** (MTBE), 1052
- Metric unit**, 12
- Meyer, Lothar**, 329
- Microscopic properties**, 12
- Microstate**, 781
- Microwave oven**, 428
- Microwaves**, 280, 428
- Milk of magnesia**, 709, 755, 949
- Millikan, Robert A.**, 41
- Mineral**, 933 (*table*)
- Miscible liquids**, 523
- Mixture**, 7
- gas, law of partial pressures and, 195
  - heterogeneous, 7
  - homogeneous, 7
  - racemic, 1009
- Moderator**, 881
- Molal boiling-point elevation constant**, 539
- Molal freezing-point depression constant**, 539
- Molality (m)**, 525
- Molar concentration**, 145
- Molar heat**
- of fusion, 502 (*table*)
  - sublimation, 504
  - of vaporization, 497, 498 (*table*)
- Molar mass**, 78, 191, 544
- Molar solubility**, 747
- Molarity (M)**, 145, 525
- Mole (mol)**, 77
- Mole fraction (X)**, 197, 525
- Mole method**, 95
- Molecular compounds**, 59
- Molecular crystals**, 493
- Molecular equation**, 123
- Molecular formula**, 52, 89
- Molecular geometry**, 415
- of coordinating compounds, 1007
  - of cycloalkanes, 1035
- Molecular mass**, 81
- Molecular models**, 52
- Molecular orbital theory**, 445
- Molecular orbitals**, 445
- bonding and antibonding, 446
  - configurations of, 448
  - delocalized, 454
  - energy level diagram of, 447, 449, 451, 452, 453
- Molecular rotation**, 784
- Molecular shapes**. *See* Molecular geometry
- Molecular speed**, 206
- distribution of, 203
  - root-mean-square, 206

- Molecular vibration, 784, 916  
 Molecular weight. *See*  
     Molecular mass  
 Molecularity, 596  
 Molecules, 50  
     chemical formulas and, 52  
     chiral, 1009, 1034  
     diatomic, 50  
     linear, 417, 435  
     nonpolar, 426  
     odd-electron, 395  
     planar, 47, 436, 442  
     polar, 426  
     polyatomic, 50  
 Monatomic gases, 173  
 Monatomic ions, 51  
 Mond, Ludwig, 939  
 Mond process, 939  
 Monodentate ligands, 1003  
 Monomers, 1061, 1066 (*table*)  
 Monoprotic acids, 128, 679  
 Moseley, Henry, 330  
 Most probable speed, 204  
 Multiple bonds, 380, 442  
 Multiple equilibria, 635  
 Multiple proportions, law  
     of, 40  
 Myoglobin, 1018
- N**
- N<sub>2</sub>*. *See* Nitrogen  
*n*-type semiconductors, 942  
 Nagasaki, 881  
 Naming compounds. *See*  
     Nomenclature  
         Naphthalene ( $C_{10}H_8$ ), 1043  
 Napoleon, 170, 494  
 Natta, Giulio, 1063  
 Natural gas, 1029  
 Natural polymers, 1063, 1067  
 Negative deviation, 537  
 Neon, 84, 357  
 Neoprene (polychloroprene), 1064  
 Neothyl, 1046  
 Neptunium, 883  
 Nernst, Walther, 830  
 Nernst equation, 830  
 Net ionic equation, 124  
 Neutralization reactions, 130,  
     151, 732  
 Neutron, 45, 865  
 Neutron activation  
     analysis, 171  
 Newlands, John, 329  
 Newton (N), 4, 175  
 Newton, Sir Isaac, 175  
 Newton's second law of motion,  
     4, 17, 175  
 Nickel, 998  
     chemical analysis of, 1020  
     extraction of, 939  
 Nitric acid ( $HNO_3$ ), 677, 972  
     Oswald process in production  
         of, 604  
     as oxidizing agent, 972  
     as strong acid, 677  
 Nitric oxide (NO), 399, 971  
 Nitride ion, 969
- Nitrogen, 355, 969  
     bonding in, 381, 453  
     common compounds of,  
         969 (*table*)  
     preparation of, 969  
 Nitrogen cycle, 904  
 Nitrogen dioxide ( $NO_2$ ), 625,  
     651, 971  
     in smog formation, 922  
 Nitrogen fixation, 903  
 Nitrogen narcosis, 201  
 Nitrogen pentoxide ( $N_2O_5$ ), 579  
 Nitroglycerin, 399  
 Nitrous oxide  $N_2O$  (laughing gas),  
     65, 971  
 Noble gas core, 310  
 Noble gases, 50, 357, 360  
 Node, 289, 446  
 Noguchi, Thomas, 562  
 Nomenclature  
     of acids, 56  
     of acids and their conjugate  
         bases, 677 (*table*)  
     of alkanes, 66, 1036  
     of alkenes, 1036  
     of alkynes, 1039  
     of anions, 57 (*table*), 1006 (*table*)  
     of aromatic compounds, 1041  
     of bases, 64  
     of cations, 58 (*table*)  
     of common compounds,  
         65 (*table*)  
     of coordination  
         compounds, 1005  
     of hydrates, 64  
     of inorganic compounds, 56, 61  
     of molecular compounds, 59, 61  
     of oxoacids, 63 (*table*)  
     of oxoanions, 63 (*table*)  
     of simple acids, 62 (*table*)  
 Nonbonding electrons, 380  
 Nonelectrolyte(s), 119  
 Nonelectrolyte solutions, colligative  
     properties of, 534  
 Nonideal gas behavior, 210  
 Nonmetal, 48, 958  
 Nonmetallic elements, 48, 958  
 Nonmetallic oxides, 358, 977  
 Nonpolar molecule, 426  
 Nonspontaneous reactions, 779  
 Nonstoichiometric  
     compounds, 962  
 Nonvolatile solutes, 534  
 Nuclear binding energy, 869  
     nuclear stability and, 869  
     per nucleon, 871  
     of uranium, 880  
 Nuclear chain reaction, 880  
 Nuclear chemistry, 864  
 Nuclear decay series, 872  
 Nuclear energy  
     from fission reactors, 881  
     from fusion reactors, 885  
     hazards of, 883  
 Nuclear equation, 865  
 Nuclear fission, 879  
     reactions, 879  
     reactors, 881  
 Nuclear fusion, 885
- Nuclear reactions, 865  
     balancing, 865  
     and decay series, 872  
     fission, 879  
     fusion, 885  
     moderator of, 881  
     nature of, 865  
     by transmutation,  
         876, 878  
 Nuclear reactors, 881, 886  
     breeder, 883  
     fission, 881  
     fusion, 886  
     heavy water, 882  
     light water, 881  
     natural, 884  
     thermal pollution  
         and, 882  
 Nuclear stability, 867  
 Nuclear transmutation, 865, 878  
 Nuclear wastes, 885  
 Nucleic acids, 1075  
 Nucleons, 46, 869  
 Nucleotide, 1076  
 Nucleus, 44  
     density of, 867  
     radius of, 867  
 Nylon (polyhexamethylene  
     adipamide), 1065  
 Nylon rope trick, 1065
- O**
- O<sub>2</sub>*. *See also* Oxygen  
     preparation of, 977  
     properties of, 977  
     solubility, 530, 533  
*O<sub>3</sub>*. *See* Ozone  
 Octahedron, 419  
 Octane number, 1051  
 Octaves, law of, 329  
 Octet rule, 380  
     exceptions to, 394  
 Odd-electron molecules, 395  
 Oil  
     as fossil fuel, 964, 1050  
     in ore preparation, 934  
 Oil, hydrogenated, 606, 964  
 Olefins. *See* Alkenes  
 Oleum, 983  
 Open system, 232  
 Optical isomers, 1009, 1034  
 Orbitals. *See* Atomic orbitals;  
     Hybrid orbitals; Molecular  
     orbitals  
 Ores, 933  
     preparation of, 934  
     roasting of, 919, 935  
 Organic chemistry, 1027  
 Organic compounds, 56, 65, 1027  
 Organic polymers. *See* Polymers  
 Orientation factor, 596  
 Orthoboric acid (boric acid), 707  
 Orthoclase. *See* Phosphoric acid  
 Osmosis, 541  
 Osmotic pressure ( $\pi$ ), 541  
 Ostwald, Wilhelm, 604  
 Oswald process, 604  
 Otto cycle, 1051
- Overlap  
     in hybridization of atomic  
         orbitals, 434  
     in molecular orbitals, 446  
     in valence bond theory, 431
- Overvoltage, 845  
 Oxalic acid, 647  
 Oxidation numbers, 135  
     assignment of, 136, 385  
     and electronegativity, 385  
     of halogens, 38  
     of metals in coordination  
         compounds, 1004  
     of nonmetallic elements, 138  
     of transition elements, 138, 1000
- Oxidation reactions, 133  
 Oxidation states. *See* Oxidation  
     numbers
- Oxidation-reduction reactions  
     (redox reactions), 132  
     balancing equations of, 815  
     quantitative aspects of, 155  
     spontaneous, 826
- Oxides  
     acidic, 359, 704, 977  
     amphoteric, 359, 704, 977  
     basic, 359, 704, 977  
 Oxidizing agent, 134  
 Oxoacid, 62, 697, 988  
 Oxoanion, 63  
 Oxyacetylene torch, 259, 1039  
 Oxygen, 356, 977  
     alkali metal reactions  
         with, 351, 945  
     allotropes of, 52, 254, 977  
     in blood, 533, 653, 734  
     hemoglobin and, 533, 653,  
         735, 1018, 1075  
     molecular orbital theory of,  
         446, 452  
     oxidation number of, 138, 385  
     paramagnetism, 446  
     and photosynthesis, 601, 903  
     preparation of, 977  
 Oxygen cycle, 904  
 Oxygen-hydrogen fuel cell, 837  
 Oxygen-propane fuel cell, 838  
 Oxyhemoglobin, 533, 653, 735,  
     1018, 1075
- Ozone, 52, 979  
     depletion of, 908  
     preparation of, 979  
     properties of, 979  
     resonance structure of, 392  
     in smog formation, 922
- P**
- p* Orbitals, 300  
*P<sub>a</sub>*, structure of, 973  
*p*-type semiconductors, 943  
 Packing efficiency, 482  
 Palladium, 962, 1020  
 Paramagnetism, 306, 446, 1014  
 Partial pressure, 195  
     Dalton's law of, 196  
 Particle accelerators, 877  
 Particle theory of light, 281  
 Particle-wave duality, 281, 289

- Pascal (Pa), 175  
 Pascal, Blaise, 175  
 Passivation, 842  
 Patina, 842  
 Pauli, Wolfgang, 305  
 Pauli exclusion principle, 305, 447, 449, 1014  
 Pauling, Linus, 383, 1070, 1074  
 Penetrating power, 306  
 Pentane ( $C_5H_{12}$ ), 1030, 1031  
 Peptide bond, 1068  
 Percent composition by mass, 85, 524  
 Percent hydrolysis, 699  
 Percent ionic character, 384  
 Percent ionization, 686  
 Percent yield, 103  
 Perchloric acid ( $HClO_4$ ), 63, 677, 697, 988  
 Perhalic acids, 988  
 Period, 48  
 Periodic group, 48  
 Periodic table, 48, 329  
     atomic radii trends in, 337  
     electron affinity trends in, 348  
     electronegativity trends in, 383  
     families in, 48  
     groups in, 48  
     historical development of, 329  
     ionization energy trends in, 345  
     periods of, 48  
 Permanent wave, 1084  
 Permanganate ion, as oxidizing agent, 155  
 Peroxide, 352, 977, 1045  
 Peroxyacetyl nitrate (PAN), 922  
 Petroleum, 1050  
 pH, 673  
     of acid-base titrations, 733, 737, 740  
     of acid rain, 919  
     blood, 734  
     of buffer solutions, 730  
     common ion effect on, 723  
     solubility equilibria and, 755  
 pH meter, 673, 732, 832  
 Pharmacokinetics, 608  
 Phase, 468  
 Phase changes, 495  
     effects of pressure on, 506  
     and entropy, 797  
     liquid-solid, 501  
     liquid-vapor, 496  
     solid-vapor, 504  
 Phase diagrams, 505, 506, 965  
 Phenolphthalein, 152, 743  
 Phenyl group, 1042  
 Phosphate buffer, 731  
 Phosphate rocks, 105, 972  
 Phosphine, 973  
 Phosphoric acid ( $H_3PO_4$ ), 128, 694, 975  
     ionization constants of, 694  
 Phosphorus, 355, 972  
     allotropes of, 973  
     in fertilizers, 105  
 Phosphorus acid ( $H_3PO_3$ ), 975  
 Phosphorus(V) oxide ( $P_2O_{10}$ ), 974  
 Phosphorus(III) oxide ( $P_2O_5$ ), 974  
 Phosphorus pentachloride ( $PCl_5$ ), 974  
 Phosphorus trichloride ( $PCl_3$ ), 974  
 Photochemical smog, 921  
 Photodissociation, 908  
 Photoelectric effect, 281  
 Photons, 281  
 Photosynthesis, 601, 903, 915  
     carbon dioxide and, 601, 915  
     chlorophyll in, 1019  
     isotope applications to, 601, 915  
     oxygen and, 601, 903  
 Physical equilibrium, 624  
 Physical properties, 10  
 Pi ( $\pi$ ) bond, 442  
 Pi ( $\pi$ ) molecular orbitals, 447  
 Pig (cast) iron, 937  
 Pipet, 12  
 $pK_a$ , 724  
 Planck, Max, 277, 280  
 Planck constant ( $\hbar$ ), 281  
 Plane-polarized light, 1009  
 Plants  
     in carbon cycle, 914  
     osmotic pressure in, 543  
 Plasma, 886  
 Platinum  
     as catalyst, 604, 923  
     as electrocatalyst, 820  
     therapeutic uses of complexes of, 1019  
 Plato, 39  
 Plutonium-239, 881, 883  
 pOH, 674  
 Polar bonds, 382  
 Polar covalent bonds, 382  
 Polar molecules, 426  
 Polar ozone hole, 910  
 Polar solvent, 120  
 Polarimeter, 1009  
 Polarizability, 471  
 Polaroid film, 1009  
 Pollution. *See* Environmental pollution  
 Polyatomic ions, 51  
 Polyatomic molecules, 50  
 Polychloroprene (neoprene), 1064  
 Poly-*cis*-isoprene, 1063  
 Polycyclic aromatic hydrocarbons, 1043  
 Polydentate ligands, 1004  
 Polyester, 1065  
 Polyethylene, 1062  
 Polyisopropene. *See* Rubber  
 Polymer(s), 1061, 1066 (table)  
 Polymerization  
     by addition, 1062  
     by condensation, 1065, 1067  
 Polypeptide, 1070  
 Polypropenes, 1062  
 Polyprotic acids, 128, 690  
 Polytetrafluoroethylene (Teflon), 989, 1062  
 Poly(vinyl chloride), 1062  
 Porphine, 1018  
 Porphyrins, 1018  
 Positive deviation, 537  
 Positron, 866  
 Pseudo first-order reaction, 585  
 Pyrex glass, 495  
 Pyrite, 980  
 Pyrometallurgy, 935  
 Potassium-40, 876  
 Potassium chlorate ( $KClO_3$ ), 198, 602  
 Potassium dichromate ( $K_2Cr_2O_7$ ), 144, 155, 815  
 Potassium hydrogen phthalate, 152  
 Potassium hydroxide (KOH), 947  
 Potassium nitrate ( $KNO_3$ ), 947  
 Potassium permanganate ( $KMnO_4$ ), 155, 816  
 Potassium superoxide ( $KO_2$ ), 351, 945  
 Potential. *See* Standard reduction potential  
 Potential energy, 231  
 Precipitate, 121  
 Precipitation reaction, 121, 750  
     ion separation by fractional, 751  
 Precision, 22  
 Prefixes  
     nomenclature, 60 (table)  
     SI unit, 13 (table)  
 Pressure, 175  
     atmospheric. *See* Atmospheric pressure  
     chemical equilibrium and changes in, 648  
     critical, 501  
     gas, 174  
     osmotic, 541  
     partial, 195  
     phase changes and, 506  
     SI unit, 175  
     vapor. *See* Vapor pressure  
 Pressure cookers, 507  
 Pressure-volume relationship of gas, 178  
 Primary pollutant, 921  
 Primary structure, 1071  
 Primary valence, 1002  
 Principal quantum number ( $n$ ), 286, 297  
 Probability, in electron distribution, 296, 300  
 Problem solving, 25, 27, 79, 682  
 Product, 91  
 Propane, 1029  
 Propane-oxygen fuel cell, 838  
 Propene, 1037  
 Properties  
     chemical, 11  
     extensive, 11  
     intensive, 11  
     macroscopic, 12  
     microscopic, 12  
     physical, 10  
 Propyne (methylacetylene), 1039  
 Protein, 1070  
     denatured, 776, 1075  
     structure of, 1070  
 Protium, 962  
 Proton, 44, 865  
 Proust, Joseph L., 40  
 Pseudo first-order reaction, 585  
 Pyrex glass, 495  
 Pyrite, 980  
 Pyrometallurgy, 935
- Q**
- Quadratic equation, 682, A-14  
 Qualitative analysis, 763  
 Qualitative data, 4  
 Quantitative analysis, 149. *See also* Acid-base titrations  
     gravimetric, 149  
     of redox reactions, 155  
 Quantitative data, 4  
 Quantum, 280  
 Quantum dot, 314  
 Quantum mechanics, 296  
 Quantum numbers, 297  
     angular momentum, 298  
     electron spin, 298  
     magnetic, 298  
     principal, 286, 297  
 Quantum theory, 277  
 Quartz  
     crystalline, 492  
     melting point of, 492  
     structure of, 495  
 Quaternary structure, 1071  
 Quicklime. *See* calcium oxide
- R**
- Racemic mixture, 1009  
 Rad, 890  
 Radiant energy, 231  
 Radiation, 41  
     biological effect of, 890  
     climate and, 915  
     electromagnetic, 279  
     ionizing, 891  
     solar. *See* Solar radiation  
 Radiation dose, 891  
 Radicals, 395, 891, 1034  
 Radioactive decay series, 872  
 Radioactive isotopes, 888  
 Radioactive waste disposal, 885  
 Radioactivity, 43  
     artificial, 877  
     biological effects of, 890  
     natural, 872  
     nuclear stability and, 867  
 Radiocarbon dating, 588, 875  
 Radiotracers, 888  
 Radium, 890, 900  
 Radius  
     atomic, 337  
     ionic, 340  
     nuclear, 867  
 Radon, 360, 923  
 Ramsay, Sir William, 360  
 Raoult, Francois M., 534  
 Raoult's law, 534  
 Rare earth series, 312  
 Rate constant, 569  
 Rate-determining step, 597  
 Rate law, 573  
 Rate of reaction, 565  
     and stoichiometry, 571  
 Rays  
     alpha, 43  
     beta, 43  
     gamma, 43

- RBE (relative biological effectiveness), 890  
 Reactants, 91  
 Reaction. *See* Chemical reactions;  
 Nuclear reactions;  
 Thermonuclear reactions  
 Reaction mechanisms, 596  
 elementary steps, 596  
 experimental study, 600  
 and molecularity of reaction, 596  
 Reaction order, 573  
 determination of, 573  
 first-order, 577  
 second-order, 584  
 zero-order, 587, 609  
 Reaction quotient ( $Q_c$ ), 641, 746, 798, 830  
 Reaction rate, 565  
 Reaction yield, 103  
 Reactors. *See* Nuclear reactors  
 Red blood cells (erythrocytes), 734, 1074  
 Red cabbage, 743  
 Red phosphorus, 973  
 Redox reactions. *See* Oxidation-reduction reactions  
 Redox titration, 155  
 Reducing agent, 134  
 Reduction potential. *See* Standard reduction potential  
 Reduction reaction, 133  
 electrolytic, 935  
 of minerals, 935  
 Refining of metals, 939  
 Relative biological effectiveness (RBE), 890  
 Relativity, theory of, 870, 877  
 Rem., 890  
 Representative (main group) elements, 332  
 Residue, 1070  
 Resonance, 392  
 Resonance structure, 392  
 Reversible reaction, 121  
 Reversible renaturation, 1075  
 Ribonucleic acid. *See* RNA  
 RNA, 1075  
 Roasting of ores, 919, 935  
 Rocks  
 age determination of, 875  
 phosphate, 105, 973  
 Röntgen, Wilhelm, 42  
 Root-mean-square speed, 206  
 Rotation  
 about bonds, 1038  
 molecular, 784  
 of plane-polarized light, 1009  
 Rotational motion, 784  
 Rubber (poly-*cis*-isopropene), 1063  
 natural, 1063  
 structure, 803, 1064  
 synthetic, 1064  
 thermodynamics of, 803  
 vulcanization, 1064  
 Rubbing (isopropyl) alcohol, 1045  
 Ruby laser, 290  
 Rust, 4, 841
- Rutherford, Ernest, 44, 330, 876  
 Rydberg Johannes, 286  
 Rydberg constant ( $R_h$ ), 286
- S**
- s Orbitals, 299  
 S<sub>z</sub>, structure of, 981  
 Sacrificial anode, 843  
 Salt(s), 130  
 hydrolysis of, 698  
 Salt bridge, 818  
 Salt hydrolysis, 698  
 Saltpeter ( $KNO_3$ ), 947  
 Saponification, 1048  
 Saturated hydrocarbons, 1029.  
*See also* Alkanes  
 Saturated solutions, 521  
 SBR (styrene-butadiene rubber), 1065  
 Scanning electron microscope, 294  
 Scattering experiment, 44  
 Schrödinger, Erwin, 296  
 Schrödinger equation, 296  
 Scientific method, 4, 6  
 Scientific notation, 18  
 Scuba diving, 200  
 Second law of motion, 4, 17, 175  
 Second law of thermodynamics, 785  
 Secondary pollutant, 921  
 Secondary structure, 1071  
 Secondary valence, 1002  
 Second-order reactions, 584  
 Seed crystals, 521  
 Semiconductors, 942  
 Semipermeable membrane, 541  
 SHE (standard hydrogen electrode), 820  
 Shell, 298  
 Shielding constant, 336  
 Shielding effect, 330, 336  
 Shroud of Turin, 589  
 SI units (International System of Units), 12  
 Sickle cell anemia, 294, 1074  
 Sigma ( $\sigma$ ) bonds, 442  
 Sigma ( $\sigma$ ) molecular orbital, 446  
 Significant figures, 19, 674, A-13  
 Silica glass. *See* Quartz  
 Silicon, 354  
 doping of, 942  
 purification of, 940  
 Silicon carbide (SiC);  
 carbonitride, 966  
 Silicon dioxide ( $SiO_2$ ), 492, 495  
 Silk, 1071  
 Silver  
 corrosion of, 842  
 extraction of, 967  
 ionization energy of, 358  
 Silver bromide ( $AgBr$ ), 748, 990  
 Silver chloride ( $AgCl$ )  
 fractional precipitation of, 751  
 gravimetric analysis of, 149  
 solubility and, 744  
 Silver iodide ( $AgI$ ), 990  
 Simple cubic cell (sc), 481
- Simplest formula, 53, 88  
 Single bond, 380  
 Slag, 937  
 Slaked lime [calcium hydroxide,  $Ca(OH)_2$ ], 950  
 Smelting of ores, 919, 935  
 Smog, 921  
 Snowmaking, 240  
 Soap, 550  
 Soda ash (sodium carbonate,  $Na_2CO_3$ ), 947  
 Soda lime glass, 495  
 Sodium, 351, 945  
 production of, 945  
 reaction with water, 139  
 Sodium acetate ( $CH_3COONa$ ), 521, 723, 727  
 Sodium acetate-acetic acid system, 723, 727  
 Sodium carbonate ( $Na_2CO_3$ ; soda ash), 947  
 Sodium chloride ( $NaCl$ ), 54, 378  
 electrolysis of aqueous, 845  
 electrolysis of molten, 843  
 melting ice with, 539  
 structure of, 54  
 Sodium fluoride, 989  
 Sodium hydroxide ( $NaOH$ );  
 caustic soda, 947  
 in saponification, 1048  
 in titrations, 152, 733  
 Sodium nitrate ( $NaNO_3$ ), 947  
 Sodium peroxide, 352  
 Sodium stearate, 550  
 Sodium tripolyphosphate, 1022  
 Soft water, 126  
 Solar energy, 231  
 Solar radiation  
 as energy source, 231  
 in hydrogen preparation, 964  
 oxygen balance and, 908  
 ozone protecting from, 909  
 Solder, 521  
 Solids  
 characteristic properties of, 10, 468  
 solutions of, in liquids, 521  
 temperature and solubility of, 529  
*See also* Crystal(s)  
 Solid-vapor equilibrium, 504  
 Solubility, 122, 747  
 common ion effect and, 753  
 gas, 530, 531, 533  
 molar, 747  
 rules of, 122  
 and temperature, 529  
 Solubility equilibria, 744  
 common ion effect and, 753  
 complex ions and, 758  
 in fractional precipitation, 752  
 pH and, 755  
 Solubility product, 744, 745 (table)  
 molar solubility and, 749 (table)  
 qualitative analysis of, 763  
 Solubility rules, 122  
 Solutes, 119  
 nonvolatile, 535  
 volatile, 535
- Solution(s), 119  
 concentration units, 145, 524  
 dilution of, 147  
 electrolyte, colligative properties of, 546  
 heat of, 260  
 ideal, 536  
 isotonic, hypertonic, and hypotonic, 542  
 nonelectrolyte, colligative properties of, 534  
 saturated, 521  
 standard, 151  
 stock, 147  
 supersaturated, 521  
 types of, 521  
 unsaturated, 521  
 Solution process, 522  
 Solution stoichiometry, 149, 151, 155, 732  
 Solvation, 523  
 Solvay, Ernest, 947  
 Solvay process, 947  
 Solvent, 119  
 Somatic effects of radiation, 891  
 Sorensen, Soren P., 673  
*sp* Hybridization, 435, 443  
*sp*<sup>2</sup> Hybridization, 436, 442  
*sp*<sup>3</sup> Hybridization, 433  
*sp*<sup>3</sup>*d* Hybridization, 441  
*sp*<sup>3</sup>*d*<sup>2</sup> Hybridization, 441  
 Space shuttle glow, 908  
 Space-filling model, 53  
 Specific heat (s), 247  
 Spectator ions, 124  
 Spectrochemical series, 1014  
 Spectrum  
 absorption, 567, 1013  
 emission, 284  
 visible. *See* Visible spectrum  
 Speed  
 of electromagnetic waves, 279  
 of light, 279  
 Maxwell speed distribution, 204  
 most probable, 204  
 root-mean-square, 206  
 Spin. *See* Electron spin  
 Spontaneous processes, 779, 792  
 Square planar complex, 1008  
 Stability  
 belt of, 990  
 nuclear, 990  
 Stability constant. *See* Formation constant  
 Stable nucleus, 990  
 Stainless steel, 939  
 Stalactites, 722  
 Stalagmites, 722  
 Standard atmospheric pressure, 176  
 Standard cell potential, 820  
 Standard electrode potential, 820. *See also* Standard reduction potential  
 Standard emf, 820  
 Standard enthalpy of formation ( $\Delta H_f^\circ$ ), 255, A-8  
 Standard enthalpy of reaction, 255  
 Standard entropies ( $S^\circ$ ), 784, A-8  
 Standard entropy of reaction, 786

- Standard free energy of formation ( $\Delta G_f^\circ$ ), 793, A-8  
 Standard free energy of reaction, 792  
 Standard hydrogen electrode, (SHE), 820  
 Standard reduction potential, 820, 823 (table)  
     of transition elements, 999  
 Standard solution, 151  
 Standard state, 254, 792  
 Standard temperature and pressure, (STP), 185  
 Standing waves, 289  
 State  
     excited, 286  
     ground, 286  
     oxidation. *See* Oxidation numbers  
     standard, 254, 792  
     thermodynamic, 234, 792  
 State functions, 234  
 State of a system, 234  
 Staudinger, Hermann, 1061  
 Steel, 937  
 Stereoisomers, 1008, 1034, 1063  
 Stern, Otto, 299  
 Stock, Alfred, 57  
 Stock solution, 147  
 Stock system, 57  
 Stoichiometric amounts, 99  
 Stoichiometry, 95  
     actual, theoretical, and percentage  
     yields in, 103  
     and gas reactions, 193  
     rate of reaction and, 571  
 Stone leprosy, 918  
 STP (standard temperature and pressure), 185  
 Straight-chain alkanes, 66, 1029  
 Stratosphere, 906  
 Strength  
     of acids and bases, 131, 675  
     molecular structure and acid, 694  
 Strong acids, 675  
 Strong bases, 676  
 Strong-field ligands, 1014  
 Strontium, 353  
 Strontium-90, 353  
 Structural formula, 53  
 Structural isomers, 1029  
 Structure, acid strength and, 693  
 Strutt, John William (Lord Rayleigh), 360  
 Styrene-butadiene rubber (SBR), 1065  
 Subatomic particles, 46, 865  
 Subcritical mass, 880  
 Sublimation, 504  
 Subshell, 298  
 Substance, 7  
 Substituted alkanes, optical isomerism of, 1034  
 Substitution reactions, 1042  
 Substrates, 607  
 Subunits, 1018, 1071  
 Sulfur, 356, 493, 980  
     allotropes of, 981  
     combustion of, 138, 235  
     common compounds of, 983  
     deposits at volcanic sites, 913  
     extraction by Frasch process, 980  
     in vulcanization process, 1064  
 Sulfur dioxide (SO<sub>2</sub>), 982  
     in acid rain, 919  
     Lewis structure of, 419  
 Sulfur hexafluoride (SF<sub>6</sub>), 396, 419, 501, 983  
 Sulfur tetrafluoride (SF<sub>4</sub>), 421  
 Sulfur trioxide (SO<sub>3</sub>), 919, 982  
 Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), 982  
     in batteries, 835  
     as diprotic acid, 128, 692, 982  
     heat of dilution, 262  
     as oxidizing agent, 983  
     production of, 982  
     as strong acid, 675  
 Sun. *See also* Solar radiation  
     emission spectrum of, 326, 915  
     nuclear fusion in, 885  
 Superconductors, 490  
 Supercooling, 503  
 Superoxide ion, 351, 977  
 Supersaturated solution, 521  
 Surface tension, 475  
 Surroundings, 232, 788  
 Syndiotactic polymers, 1063  
 Syngas, 968  
 Synthetic rubbers (elastomers), 1064  
 System  
     closed, 232  
     defined, 232  
     isolated, 232  
     open, 232  
     state of, 234  
**T**  
 Technetium-99, 889  
 Teflon (polytetrafluoroethylene), 989, 1062  
 Temperature  
     chemical equilibria and changes, 650  
     critical, 501  
     and rate of reaction, 590  
     solubility and, 529  
     and water vapor pressure, 199 (table)  
 Temperature scales  
     Celsius, 15, 182  
     Fahrenheit, 15  
     Kelvin, 15, 182  
 Temporary dipole, 471  
 Termites, 1029  
 Termolecular reactions, 396  
 Ternary compound, 57  
 Tertiary structure, 1071  
 Tetracarbonylnickel [Ni(CO<sub>4</sub>)], 939  
 Tetraethyllead [(C<sub>2</sub>H<sub>5</sub>)<sub>4</sub>Pb], 1052  
 Tetrahedral complex, 1008  
 Tetrahedron, 418  
 Theoretical yield, 103  
 Theory, 5  
 Therapeutic chelating agents, 1020  
 Thermal energy, 231  
 Thermal motion, 205  
 Thermal (slow) neutrons, 879  
 Thermal pollution, 530, 882  
 Thermite reaction, 259, 951  
 Thermochemical equation, 243  
 Thermochemistry, 232  
 Thermodynamic efficiency, 793, 838  
 Thermodynamics, 234, 778  
     first law of, 234  
     in living systems, 802  
     second law of, 785  
     third law of, 789  
 Thermonuclear bomb, 887  
 Thermonuclear reactions, 885  
 Thermosphere, 906  
 Thioacetamide, 982  
 Thiosulfate ions, 888  
 Third law of thermodynamics, 789  
 Thomson, George P., 293  
 Thomson, Joseph J., 41, 43  
 Thorium-232, 883  
 Three Mile Island nuclear reactor, 885  
 Threshold frequency, 282  
 Thymine, 1076  
 Thyroid gland, 889  
 Thyroxine, 990  
 Time  
     SI unit of, 13  
 Tin, 354, 494  
 Tincture of iodine, 990  
 Titanium dioxide, 721  
 Titanium(III) chloride (TiCl<sub>3</sub>), 1063  
 Titration  
     acid-base, 151, 732  
     redox, 155  
 Titration curve, 733, 737, 740  
 Tokamak, 886  
 Toluene, 536  
 Tooth decay, 848  
 Torr, 176  
 Torricelli, Evangelista, 176  
 Toxicity  
     of arsenic, 170, 1085  
     of carbon dioxide, 533, 926  
     of carbon monoxide, 926  
     of carbon tetrachloride, 1034  
     of chloroform, 1034  
     of cyanide, 966  
     of deuterium oxide, 963  
     of formaldehyde, 926  
     of gases, 174  
     of hydrogen sulfide, 982  
     of methanol, 1045  
     of ozone, 922, 980  
     of plutonium-239, 883  
     of radon-222, 924  
     of smog, 921  
     of strontium-90, 353  
     of sulfur dioxide, 982  
     of tetracarbonylnickel, 939  
     of white phosphorus, 973  
 Tracers, 888  
 Trans isomers. *See* Cis-trans isomers  
 Transition metal(s), 57, 312, 331, 997  
     electron configuration of, 335, 998  
     oxidation numbers of, 138, 1000  
     properties of, 998  
 Transition metal oxides, 705  
 Transition state, 591  
 Translational motion, 784  
 Transmutation, nuclear, 876, 878  
 Transpiration, 543  
 Transuranium elements, 878 (table)  
 Triethylaluminum [Al(C<sub>2</sub>H<sub>5</sub>)<sub>3</sub>], 1063  
 Trigonal bipyramidal, 418  
 Trinitrotoluene (TNT), 881  
 Triple bonds, 381, 443  
 Triple point, 505  
 Tripolyphosphate, 1022  
 Tripositive ion, 340  
 Triprotic acid, 128, 694  
 Tritium, 46, 877, 962  
 Trona, 947  
 Troposphere, 906  
 Tyndall, John, 549  
 Tyndall effect, 549  
 Tyvek, 1062
- U**
- Uncertainty principle, 295  
 Unimolecular reaction, 596  
 Unipositive ion, 340  
 Unit, SI, 12  
 Unit cells, 479  
 Unsaturated hydrocarbons, 1036  
 Unsaturated solutions, 521  
 Unshared electron pairs, 380  
 Uranium  
     fission product of, 879  
     isotopes of, 47  
 Uranium decay series, 873  
 Uranium oxide (U<sub>3</sub>O<sub>8</sub>), 882  
 Uranium-235, 47, 879, 880, 881  
 Uranium-238, 47, 883  
     abundance of, 883  
     dating with, 875  
     decay of, 873  
 Urea  
     in fertilizer, 105  
     preparation of, 1028  
     treatment of sickle cell anemia, 1074
- V**
- Valence, 1002  
 Valence band, 941  
 Valence bond theory, 431  
 Valence electrons, 332  
 Valence shell, 415  
 Valence shell expansion, 441  
 Valence-shell electron-pair repulsion (VSEPR) model, 415  
     and molecules in which central atom has no lone pairs, 415  
     and molecules in which central atom has one or more lone pairs, 419  
 Valine, 1076  
 Van der Waals, Johannes D., 211  
 Van der Waals constants, 212 (table)  
 Van der Waals equation, 212  
 Van der Waals forces, 469  
 Van Meegeren, Han, 900  
 Vanadium(V) oxide (V<sub>2</sub>O<sub>5</sub>), 983

van't Hoff, Jacobus, 536  
 van't Hoff factor (*i*), 546  
 Vapor, 174  
 Vapor pressure, 199, 496  
 Vaporization (evaporation), 496  
     entropy and, 783  
     molar heat of, 497, 498 (table)  
 Vapor-pressure lowering, 534  
 Vector, 426  
 Vermeer, Jan, 900  
 Vibrational motion, 784, 915  
 Viscosity, 476  
 Visible spectrum, 280, 1013  
 Vision, 1038  
 Vitamin C, 680  
 Volatile solutes, 535  
 Volcanoes, 913  
 Volt, 826  
 Voltage, 819. *See also*  
     Electromotive force  
 Voltaic (galvanic) cell, 818  
 Voltmeter, 819  
 Volume, 11  
     chemical equilibria and  
     changes in, 648  
     constant, 248  
     SI unit of, 14  
 Volumetric flask, 12, 146  
 VSEPR. *See* Valence-shell  
     electron-pair repulsion  
     model  
 Vulcanization, 1064

**W**

Waage, Peter, 626  
 Waste disposal, radioactive  
     waste, 885  
 Water  
     acid-base properties of, 670  
     autoionization of, 671  
     density of, 478  
     dipole moment of, 427  
     electrolysis of, 844  
     fluoridation of, 989  
     hard, 126  
     hydrogen bonds in, 477  
     ion product constant ( $K_w$ ) of, 671  
     as moderator, 881  
     phase diagram of, 506  
     soft, 126  
     specific heat of, 247, 477  
     structure of, 477  
     surface tension of, 475  
     vapor pressure of, 199 (table)  
     vibrational motions,  
         784, 915  
     viscosity of, 476  
 Water gas, 960  
 Water vapor, pressure of  
     199 (table)  
 Watson, James, 1076  
 Watt, 953  
 Wave function, 296  
 Wave mechanics, 296

Wavelength, 277

color and, 280, 1013

radiation and, 279

Wave-particle duality, 281, 289

Waves, 277

amplitude, 277

electromagnetic, 279

frequency, 277

interference, 446

length, 277

properties of, 277

standing, 290

Weak acids

defined, 676

ionization constants of, 680, 692

strong base reactions with, 736

Weak bases

defined, 677

ionization constants of, 687

strong acid reactions with, 739

Weak-field ligands, 1014

Weight, 13

atomic. *See* Atomic mass

molecular. *See* Molecular mass

percentage, composition by. *See*  
     Percentage composition  
     by mass

Werner, Alfred, 1002

White lead [ $Pb_3(OH)_2(CO_3)_2$ ], 900

White phosphorus, 973

Wohler, F., 1028

Wood alcohol. *See* Methanol

Wood's metal, 563

Work, 231, 236

    electrical, 826

    free energy and, 826

    and gas expansion, 237

Work function, 282

**X**

X rays, 42

    diffraction of, 486

    periodic table and, 330

Xenon, 357

**Y**

Yields

    actual, 103

    percent, 103

    theoretical, 103

**Z**

Zero electron density (node),  
     289, 446

Zero-order reactions, 587, 609

Ziegler, Karl, 1063

Zincblende, 488

Zinc

    in batteries, 834

    cathodic protection with, 842

Zinc sulfide (ZnS), 42

Zone refining, 940

John B. Lacson Foundation Maritime University-Molo, Inc.  
 (ILOILO MARITIME ACADEMY)  
 Iloilo City

Accession Number: 2220e-m

Call Number:

540  
 C455  
 2013

