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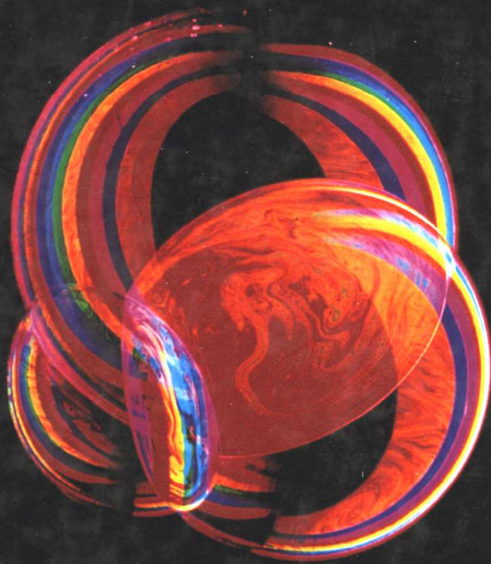

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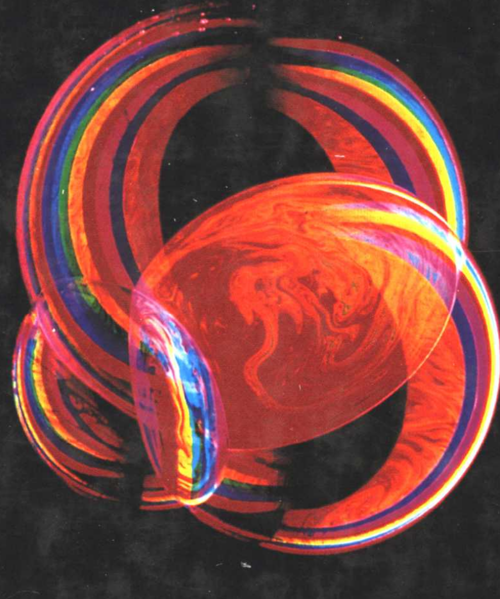

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University of Illinois

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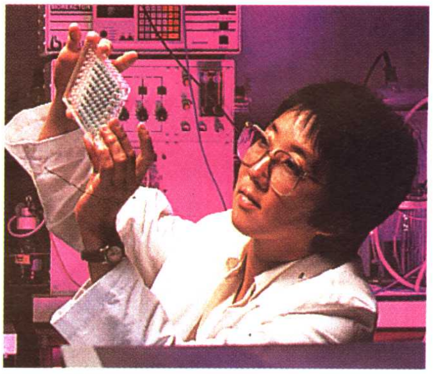
Contents

To the Professor xv
To the Student xxi
About the Author xxiii

Chapter 1 Chemical Foundations **1**

1.1 Chemistry: An Overview 2
1.2 The Scientific Method 4
1.3 Units of Measurement 6
• **Chemical Impact** Observations, Theories, and the Planets 7
1.4 Uncertainty in Measurement 10
1.5 Significant Figures and Calculations 13
1.6 Dimensional Analysis 17
1.7 Temperature 21
1.8 Density 25
1.9 Classification of Matter 26
Summary 30
Key Terms 31
Questions and Exercises 32



Chapter 2 Atoms, Molecules, and Ions **39**

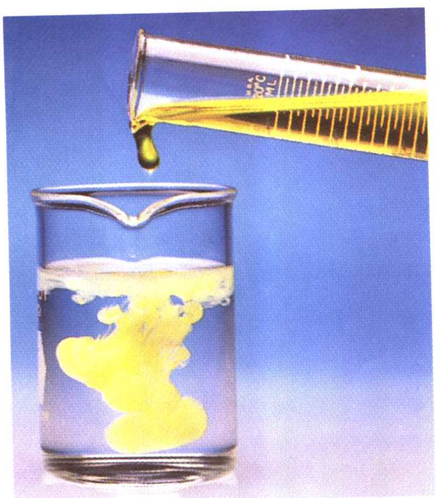
2.1 The Early History of Chemistry 40
2.2 Fundamental Chemical Laws 41
2.3 Dalton's Atomic Theory 45
2.4 Early Experiments to Characterize the Atom 47
• **Chemical Impact** Berzelius, Selenium, and Silicon 48
2.5 The Modern View of Atomic Structure: An Introduction 52
2.6 Molecules and Ions 54
2.7 An Introduction to the Periodic Table 57
2.8 Naming Simple Compounds 59
• **Chemical Impact** Buckminsterfullerene: A New Form of Carbon 63
Summary 70
Key Terms 71
Questions and Exercises 73

Chapter 3 Stoichiometry **79**

3.1 Atomic Masses 80
3.2 The Mole 83
• **Chemical Impact** Elemental Analysis Catches Elephant Poachers 85
3.3 Molar Mass 87
• **Chemical Impact** Measuring the Masses of Large Molecules or Making Elephants Fly 88

3.4 Percent Composition of Compounds 91
3.5 Determining the Formula of a Compound 93
3.6 Chemical Equations 100
3.7 Balancing Chemical Equations 102
3.8 Stoichiometric Calculations: Amounts of Reactants and Products 107
• **Chemical Impact** Sulfuric Acid: The Most Important Chemical 109
3.9 Calculations Involving a Limiting Reactant 112
Summary 122
Key Terms 123
Questions and Exercises 124

Chapter 4 Types of Chemical Reactions and Solution Stoichiometry **133**
4.1 Water, the Common Solvent 134
4.2 The Nature of Aqueous Solutions: Strong and Weak Electrolytes 136
• **Chemical Impact** Arrhenius, a Man with Solutions 140
4.3 The Composition of Solutions 141
4.4 Types of Chemical Reactions 148
4.5 Precipitation Reactions 148
4.6 Describing Reactions in Solution 153
4.7 Stoichiometry of Precipitation Reactions 155
4.8 Acid–Base Reactions 157
4.9 Oxidation–Reduction Reactions 164
• **Chemical Impact** Iron Zeroes in on Pollution 166
4.10 Balancing Oxidation–Reduction Equations 171
• **Chemical Impact** Aging: Does It Involve Oxidation? 172
Summary 178
Key Terms 179
Questions and Exercises 180



Chapter 5 Gases **187**
5.1 Pressure 188
5.2 The Gas Laws of Boyle, Charles, and Avogadro 190
5.3 The Ideal Gas Law 196
5.4 Gas Stoichiometry 201
5.5 Dalton's Law of Partial Pressures 205
• **Chemical Impact** The Chemistry of Air Bags 207
• **Chemical Impact** Scuba Diving 210
5.6 The Kinetic Molecular Theory of Gases 210
5.7 Effusion and Diffusion 218
5.8 Real Gases 220
5.9 Chemistry in the Atmosphere 224
• **Chemical Impact** Acid Rain: A Growing Problem 226
Summary 228
Key Terms 229
Questions and Exercises 230

Chapter 6 Thermochemistry 239

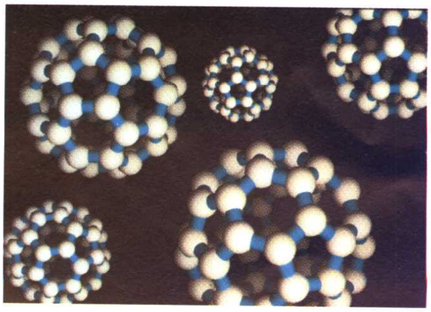
6.1 The Nature of Energy 240
6.2 Enthalpy and Calorimetry 246
• **Chemical Impact** Firewalking: Magic or Science? 252
6.3 Hess's Law 254
6.4 Standard Enthalpies of Formation 257
6.5 Present Sources of Energy 265
• **Chemical Impact** Sulfur-Eating Bacteria Clean Up Coal 269
6.6 New Energy Sources 270
• **Chemical Impact** Heat Packs 275
• **Chemical Impact** Nature Has Hot Plants 276
Summary 277
Key Terms 278
Questions and Exercises 279

Chapter 7 Atomic Structure and Periodicity 287

7.1 Electromagnetic Radiation 288
• **Chemical Impact** Flies that Dye 289
7.2 The Nature of Matter 290
• **Chemical Impact** Solar Polar Bears 291
7.3 The Atomic Spectrum of Hydrogen 295
7.4 The Bohr Model 297
• **Chemical Impact** Fireworks 300
7.5 The Quantum Mechanical Model of the Atom 302
7.6 Quantum Numbers 305
7.7 Orbital Shapes and Energies 307
7.8 Electron Spin and the Pauli Principle 308
7.9 Polyelectronic Atoms 310
7.10 The History of the Periodic Table 312
7.11 The Aufbau Principle and the Periodic Table 314
7.12 Periodic Trends in Atomic Properties 322
7.13 The Properties of a Group: The Alkali Metals 328
• **Chemical Impact** Lithium: Behavior Medicine 332
Summary 333
Key Terms 334
Questions and Exercises 335

Chapter 8 Bonding: General Concepts 343

8.1 Types of Chemical Bonds 344
8.2 Electronegativity 347
8.3 Bond Polarity and Dipole Moments 349
8.4 Ions: Electron Configurations and Sizes 353
8.5 Formation of Binary Ionic Compounds 357
8.6 Partial Ionic Character of Covalent Bonds 362
8.7 The Covalent Chemical Bond: A Model 363
8.8 Covalent Bond Energies and Chemical Reactions 366
8.9 The Localized Electron Bonding Model 370
8.10 Lewis Structures 370
8.11 Exceptions to the Octet Rule 374



8.12 Resonance 378
8.13 Molecular Structure: The VSEPR Model 384
- **Chemical Impact** Chemical Structure and Communication: Semiochemicals 394

Summary 396
Key Terms 397
Questions and Exercises 398

Chapter 9 Covalent Bonding: Orbitals 407

9.1 Hybridization and the Localized Electron Model 407
9.2 The Molecular Orbital Model 420
9.3 Bonding in Homonuclear Diatomic Molecules 424
9.4 Bonding in Heteronuclear Diatomic Molecules 430
9.5 Combining the Localized Electron and Molecular Orbital Models 432
Summary 434
Key Terms 435
Questions and Exercises 436

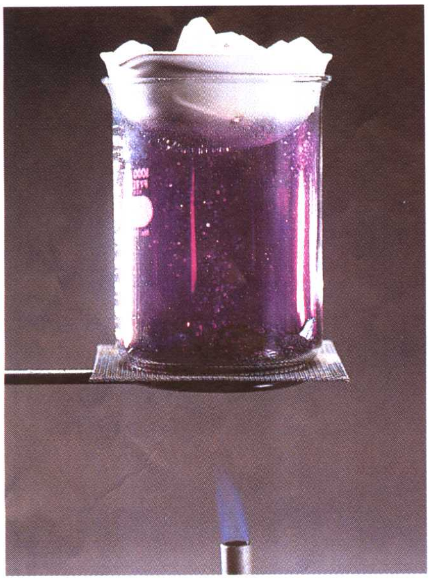
Chapter 10 Liquids and Solids 443

10.1 Intermolecular Forces 444
10.2 The Liquid State 448
10.3 An Introduction to Structures and Types of Solids 450
10.4 Structure and Bonding in Metals 455
- **Chemical Impact** Superconductivity 460

10.5 Carbon and Silicon: Network Atomic Solids 462
10.6 Molecular Solids 468
- **Chemical Impact** Gallium Arsenide Lasers 470

10.7 Ionic Solids 470
10.8 Vapor Pressure and Changes of State 474
10.9 Phase Diagrams 482
- **Chemical Impact** Making Diamonds at Low Pressures: Fooling Mother Nature 488
- **Chemical Impact** Transistors and Printed Circuits 489
- **Chemical Impact** Diamonds—A Computer's Best Friend? 490

Summary 492
Key Terms 494
Questions and Exercises 494



Chapter 11 Properties of Solutions 505

11.1 Solution Composition 506
- **Chemical Impact** An Energy Solution 508

11.2 The Energies of Solution Formation 510
- **Chemical Impact** Miracle Solvents 514

11.3 Factors Affecting Solubility 515
- **Chemical Impact** Hydrogen Beer 517
- **Chemical Impact** The Lake Nyos Tragedy 518

11.4 The Vapor Pressures of Solutions 520

11.5 Boiling-Point Elevation and Freezing-Point Depression 527
11.6 Osmotic Pressure 531
11.7 Colligative Properties of Electrolyte Solutions 536
11.8 Colloids 537
• **Chemical Impact** Organisms and Ice Formation 538
Summary 540
Key Terms 541
Questions and Exercises 542

Chapter 12 Chemical Kinetics 549

12.1 Reaction Rates 551
12.2 Rate Laws: An Introduction 554
12.3 Determining the Form of the Rate Law 557
12.4 The Integrated Rate Law 561
12.5 Rate Laws: A Summary 572
12.6 Reaction Mechanisms 573
12.7 A Model for Chemical Kinetics 576
12.8 Catalysis 582
• **Chemical Impact** Automobiles: Air Purifiers? 585
• **Chemical Impact** Enzymes: Nature's Catalysts 586
Summary 589
Key Terms 591
Questions and Exercises 591

Chapter 13 Chemical Equilibrium 601

13.1 The Equilibrium Condition 602
13.2 The Equilibrium Constant 605
13.3 Equilibrium Expressions Involving Pressures 610
13.4 Heterogeneous Equilibria 613
13.5 Applications of the Equilibrium Constant 615
13.6 Solving Equilibrium Problems 625
13.7 Le Châtelier's Principle 630
Summary 637
Key Terms 638
Questions and Exercises 639

Chapter 14 Acids and Bases 647

14.1 The Nature of Acids and Bases 648
14.2 Acid Strength 650
14.3 The pH Scale 656
14.4 Calculating the pH of Strong Acid Solutions 658
14.5 Calculating the pH of Weak Acid Solutions 660
• **Chemical Impact** Household Chemistry 667
14.6 Bases 670
• **Chemical Impact** Amines 673
14.7 Polyprotic Acids 676
14.8 Acid–Base Properties of Salts 683
14.9 The Effect of Structure on Acid–Base Properties 689

14.10 Acid–Base Properties of Oxides 691
14.11 The Lewis Acid–Base Model 692
- **Chemical Impact** Self-Destructing Paper 693

14.12 Strategy for Solving Acid–Base Problems: A Summary 695
Summary 696
Key Terms 698
Questions and Exercises 699

Chapter 15 Applications of Aqueous Equilibria 707

Acid–Base Equilibria
15.1 Solutions of Acids or Bases Containing a Common Ion 708
15.2 Buffered Solutions 710
15.3 Buffer Capacity 720
15.4 Titrations and pH Curves 724
15.5 Acid–Base Indicators 739

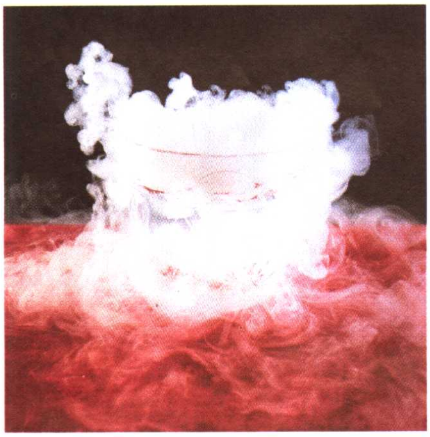
Solubility Equilibria
15.6 Solubility Equilibria and the Solubility Product 744
15.7 Precipitation and Qualitative Analysis 754

Complex Ion Equilibria
15.8 Equilibria Involving Complex Ions 760
- **Chemical Impact** The Chemistry of Teeth 766

Summary 767
Key Terms 768
Questions and Exercises 769

Chapter 16 Spontaneity, Entropy, and Free Energy 777

16.1 Spontaneous Processes and Entropy 779
16.2 Entropy and the Second Law of Thermodynamics 784
16.3 The Effect of Temperature on Spontaneity 785
16.4 Free Energy 788
16.5 Entropy Changes in Chemical Reactions 791
16.6 Free Energy and Chemical Reactions 795
16.7 The Dependence of Free Energy on Pressure 800
16.8 Free Energy and Equilibrium 804
16.9 Free Energy and Work 808
Summary 811
Key Terms 812
Questions and Exercises 813



Chapter 17 Electrochemistry 821

17.1 Galvanic Cells 822
17.2 Standard Reduction Potentials 824
17.3 Cell Potential, Electrical Work, and Free Energy 831
17.4 Dependence of Cell Potential on Concentration 835
17.5 Batteries 841
17.6 Corrosion 843
- **Chemical Impact** Refurbishing the Lady 846
- **Chemical Impact** Paint that Stops Rust—Completely 847

17.7 Electrolysis 847
• **Chemical Impact** The Chemistry of Sunken Treasure 852
17.8 Commercial Electrolytic Processes 853
• **Chemical Impact** Batteries of the Future 856
Summary 860
Key Terms 862
Questions and Exercises 863

Chapter 18 The Representative Elements: Groups 1A Through 4A 871

18.1 A Survey of the Representative Elements 872
18.2 The Group 1A Elements 877
18.3 Hydrogen 880
18.4 The Group 2A Elements 882
18.5 The Group 3A Elements 885
18.6 The Group 4A Elements 887
• **Chemical Impact** Concrete Learning 889
Summary 891
Key Terms 892
Questions and Exercises 892

Chapter 19 The Representative Elements: Groups 5A Through 8A 897

19.1 The Group 5A Elements 898
19.2 The Chemistry of Nitrogen 899
• **Chemical Impact** A Blanket of Nitrogen 905
• **Chemical Impact** Nitrous Oxide: Laughing Gas that Propels Whipped Cream and Cars 910
19.3 The Chemistry of Phosphorus 912
19.4 The Group 6A Elements 915
19.5 The Chemistry of Oxygen 916
19.6 The Chemistry of Sulfur 918
19.7 The Group 7A Elements 923
• **Chemical Impact** Photography 924
• **Chemical Impact** Automatic Sunglasses 930
19.8 The Group 8A Elements 931
Summary 933
Key Terms 934
Questions and Exercises 935

Chapter 20 Transition Metals and Coordination Chemistry 941

20.1 The Transition Metals: A Survey 942
20.2 The First-Row Transition Metals 948
• **Chemical Impact** Titanium Makes Great Bicycles 950
20.3 Coordination Compounds 954
• **Chemical Impact** Alfred Werner: Coordination Chemist 958
20.4 Isomerism 959
• **Chemical Impact** The Importance of Being *cis* 962

20.5 Bonding in Complex Ions: The Localized Electron Model 965
20.6 The Crystal Field Model 967
- **Chemical Impact** Transition Metal Ions Lend Color to Gems 972

20.7 The Biologic Importance of Coordination Complexes 974
20.8 Metallurgy and Iron and Steel Production 978
Summary 986
Key Terms 988
Questions and Exercises 989

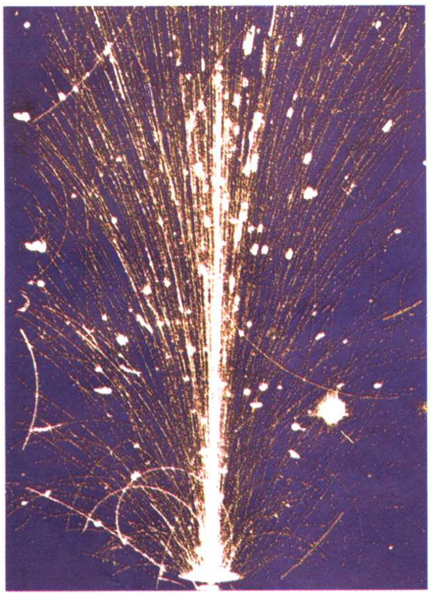
Chapter 21 The Nucleus: A Chemist's View 995

21.1 Nuclear Stability and Radioactive Decay 996
21.2 The Kinetics of Radioactive Decay 1001
- **Chemical Impact** Stellar Nucleosynthesis 1005

21.3 Nuclear Transformations 1005
21.4 Detection and Uses of Radioactivity 1007
21.5 Thermodynamic Stability of the Nucleus 1011
21.6 Nuclear Fission and Nuclear Fusion 1015
- **Chemical Impact** Nuclear Power: Could It Stage a Comeback? 1019
- **Chemical Impact** Nuclear Waste Disposal 1020

21.7 Effects of Radiation 1022
- **Chemical Impact** Nuclear Physics: An Introduction 1024

Summary 1026
Key Terms 1027
Questions and Exercises 1027



Chapter 22 Organic Chemistry 1033

22.1 Alkanes: Saturated Hydrocarbons 1034
22.2 Alkenes and Alkynes 1042
22.3 Aromatic Hydrocarbons 1046
22.4 The Petrochemical Industry 1048
22.5 Hydrocarbon Derivatives 1052
22.6 Polymers 1058
22.7 The Polymer Industry 1062
- **Chemical Impact** Wallace Hume Carothers 1065
- **Chemical Impact** The Mechanism of Methane Combustion 1072
- **Chemical Impact** Plastic that Talks and Listens 1073

Summary 1073
Key Terms 1075
Questions and Exercises 1075

Chapter 23 Biochemistry 1085

23.1 Proteins 1087
23.2 Carbohydrates 1097
23.3 Nucleic Acids 1102

23.4 Lipids 1107
• **Chemical Impact** The Chemistry of Vision 1112
Summary 1113
Key Terms 1114
Questions and Exercises 1115

Appendix 1 Mathematical Procedures A1
A1.1 Exponential Notation A1
A1.2 Logarithms A4
A1.3 Graphing Functions A6
A1.4 Solving Quadratic Equations A8
A1.5 Uncertainties in Measurements A10

Appendix 2 The Quantitative Kinetic Molecular Model A13

Appendix 3 Spectral Analysis A17

Appendix 4 Selected Thermodynamic Data A21

Appendix 5 Equilibrium Constants and Reduction Potentials A24
A5.1 Values of K_a for Some Common Monoprotic Acids A24
A5.2 Stepwise Dissociation Constants for Several Common Polyprotic Acids A24
A5.3 Values of K_b for Some Common Weak Bases A25
A5.4 K_{sp} Values at 25°C for Common Ionic Solids A25
A5.5 Standard Reduction Potentials at 25°C (298 K) for Many Common Half-Reactions A26

Glossary A27

Answers to Selected Exercises A41

Photo Credits A67

Index A69

Chapter 1

Chemical Foundations

Contents

1.1 Chemistry: An Overview
1.2 The Scientific Method
1.3 Units of Measurement
1.4 Uncertainty in Measurement
1.5 Significant Figures and Calculations
1.6 Dimensional Analysis
1.7 Temperature
1.8 Density
1.9 Classification of Matter

When you start your car, do you think about chemistry? Probably not, but you should. The power to start your car is furnished by a lead storage battery. How does this battery work, and what does it contain? When a battery goes dead, what does that mean? If you use a friend's car to "jump start" your car, did you know that your battery could explode? How can you avoid such an unpleasant possibility? What is in the gasoline that you put in your tank, and how does it furnish the energy to drive to school? What is the vapor that comes out of the exhaust pipe, and why does it cause air pollution? Your car's air conditioner probably has a substance in it that is leading to the destruction of the ozone layer in the upper atmosphere. What are we doing about that? And why is the ozone layer important anyway?

All these questions can be answered by understanding some chemistry. In fact, we'll consider the answers to all these questions in this text.

Chemistry is all around you all the time. You are able to read and understand this sentence because chemical reactions are occurring in your brain. The food you ate for breakfast or lunch is now furnishing energy through chemical reactions. Trees and grass grow because of chemical changes.

Chemistry also crops up in some unexpected places. When archaeologist Luis Alvarez was studying in college, he probably didn't realize that the chemical elements iridium and niobium would make him very famous when they helped him solve the problem of the disappearing dinosaurs. For decades scientists had wrestled with the mystery of why the dinosaurs, after ruling the earth for millions of years, suddenly became extinct 65 million years ago. In studying core samples of rocks dating back to that period, Alvarez and his coworkers recognized unusual levels of iridium and niobium in these samples—levels much more characteristic of extraterrestrial bodies than of the earth. Based on these observations

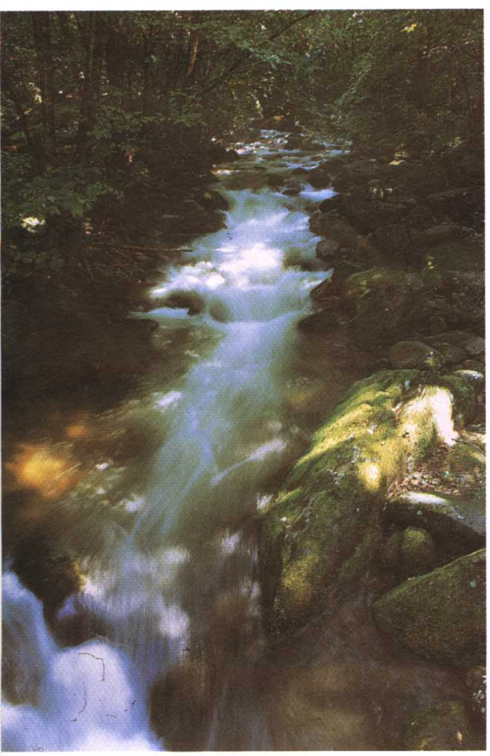
Sea anemones release a chemical alarm when attacked by a fish. This waterborne signal spreads through the dense colony of anemones, warning each individual to draw in its tentacles and close its mouth.

Alvarez hypothesized that a large meteor may have hit the earth 65 million years ago, raising so much dust that the dinosaurs' food couldn't grow and they died—almost instantly in the geologic timeframe.

Chemistry is also important to historians. Did you realize that lead poisoning probably was a significant contributing factor to the decline of the Roman Empire? The Romans had high exposure to lead from lead-glazed pottery, lead water pipes, and a sweetening syrup called *sapa* that was prepared by boiling down grape juice in lead-lined vessels. It turns out that one reason for sapa's sweetness was lead acetate ("sugar of lead") that formed as the juice was cooked down. Lead poisoning with its symptoms of lethargy and mental malfunctions could have certainly contributed to the demise of the Roman society.

Chemistry is also apparently very important in determining a person's behavior. Various studies have shown that many personality disorders can be linked directly to imbalances of trace elements in the body. For example, studies on the inmates at Stateville Prison in Illinois link low cobalt levels with violent behavior. Also, lithium salts have been shown to be very effective in controlling the effects of manic depressive disease, and you've probably at some time in your life felt a special "chemistry" for another person. Studies suggest there is literally chemistry going on between two people who are attracted to each other. "Falling in love" apparently causes changes in the chemistry of the brain; chemicals are produced that give that "high" associated with a new relationship. Unfortunately, these chemical effects seem to wear off over time, even if the relationship persists and grows.

The importance of chemistry in the interactions of people should not really surprise us, since we know that insects communicate by emitting and receiving chemical signals via molecules called *pheromones*. For example, ants have a very complicated set of chemical signals to signify food sources, danger, etc. Also, various female sex attractants have been isolated and used to lure males into traps to control insect populations. It would not be surprising if humans also emitted chemical signals that we were not aware of on a conscious level. Thus chemistry is pretty interesting and pretty important. The main goal of this text is to help you understand the concepts of chemistry so that you can better appreciate the world around you and can be more effective in whatever career you choose.



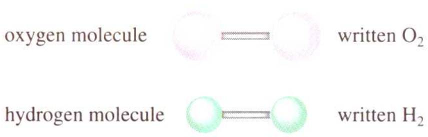
The water in this stream in the Great Smoky Mountains is composed of hydrogen and oxygen atoms.

1.1 Chemistry: An Overview

Although we will discuss all these things in much more detail as we proceed through this text, let's preview here what chemistry is about. Chemistry is fundamentally concerned with how one substance changes to another—how plants grow by absorbing water and carbon dioxide, how humans manufacture the proteins we need to live from the food we consume, how smog forms in areas with traffic congestion, how nylon for jackets and tents is made, and on and on.

Through processes we will discuss in this text scientists have learned that the matter of the universe is composed of atoms. It is hard to believe, but our universe with its incredible diversity is made of only a hundred or so different types of atoms. You can think of these approximately 100 atoms as the letters in an alphabet out of which all the "words" in the universe are made. It is the way the atoms are organized in a given substance that determines the properties of that substance. For example, water, one of the most common and important substances on earth, is composed of two types of atoms: hydrogen and oxygen. There are two hydrogen atoms and one oxygen atom bound together to form the water molecule:

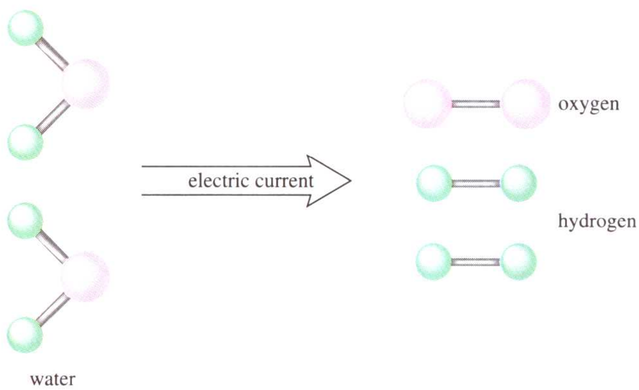
When an electric current passes through it, water is decomposed to hydrogen and oxygen. These *chemical elements* themselves exist naturally as diatomic (two-atom) molecules:



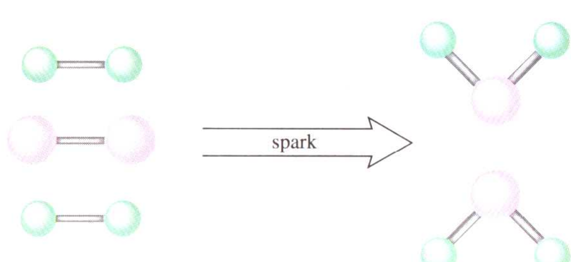
A scientist studying the photosynthesis of wheat.

We can represent the decomposition of water to its component elements, hydrogen and oxygen, as follows:

Molecular Models: O_2, H_2, H_2O



Notice that it takes two molecules of water to furnish the right number of oxygen and hydrogen atoms to allow for the formation of the two-atom molecules. This reaction explains why the battery in your car can explode if you jump start it improperly. When you hook up the jumper cables, current flows through the dead battery, which contains water (and other things), and causes hydrogen and oxygen to form by decomposition of some of the water. A spark can cause this accumulated hydrogen and oxygen to explode, forming water again.



This example illustrates two of the fundamental concepts of chemistry: (1) matter is composed of various types of atoms, and (2) one substance changes to another by reorganizing the way the atoms are attached to each other.

These are core ideas of chemistry, and we will have much more to say about them.

Science: A Process for Understanding Nature and Its Changes

How do you tackle the problems that confront you in real life? Think about your trip to school. If you live in a city, traffic is undoubtedly a problem you confront daily. How do you decide the best way to drive to school? If you are new in town, you first get a map and look at the possible ways to make the trip. Then you might collect information from people who know the area about the advantages and disadvantages of various routes. Based on this information, you probably try to predict the best route. However, you can only find the best route by trying several of them and comparing the results. After a few experiments with the various possibilities, you will probably be able to select the best way. What you are doing in solving this everyday problem is applying the same process that scientists use to study nature. The first thing you did was collect relevant data. Then you made a prediction, and then you tested it by trying it out. This process contains the fundamental elements of science.

1. Making observations (collecting data)
2. Making a prediction (formulating a hypothesis)
3. Do experiments to test the prediction (testing the hypothesis).

Scientists call this process the *scientific method.* We will discuss this in more detail in the next section. One of life's most important activities is solving problems—not "plug and chug" exercises, but real problems. Problems that have new facets to them—that involve things you may have never confronted before. The more creative you are at solving these problems, the more effective you will be in your career and your personal life. Part of the reason for learning chemistry, therefore, is to become a better problem solver. Chemists are usually excellent problem solvers, because to master chemistry, you have to master the scientific approach. Chemical problems are frequently very complicated—there is usually no neat and tidy solution. Often it is difficult to know where to begin.

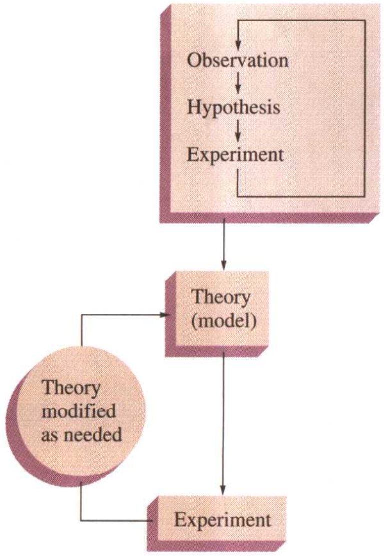


Figure 1.1
The fundamental steps of the scientific method.

1.2 The Scientific Method

Science is a framework for gaining and organizing knowledge. Science is not simply a set of facts but is also a plan of action—a *procedure* for processing and understanding certain types of information. Scientific thinking is useful in all aspects of life, but in this text we will use it to understand how the chemical world operates. As we have said in our previous discussion, the process that lies at the center of scientific inquiry is called the **scientific method.** There are actually many scientific methods, depending on the nature of the specific problem under study and on the particular investigator involved. However, it is useful to consider the following general framework for a generic scientific method (see Fig. 1.1):

Steps in the Scientific Method

1. *Making observations.* Observations may be *qualitative* (the sky is blue; water is a liquid) or *quantitative* (water boils at 100°C; a certain chemistry book weighs 2 kilograms). A qualitative observation does not involve a number. A quantitative observation (called a *measurement*) involves both a number and a unit.
2. *Formulating hypotheses.* A **hypothesis** is a *possible* explanation for an observation.
3. *Performing experiments.* An experiment is carried out to test a hypothesis. This involves gathering new information that enables a scientist to decide whether or not the hypothesis is valid—that is, whether it is supported by the new information learned from the experiment. Experiments always produce new observations, and this brings the process back to the beginning again.

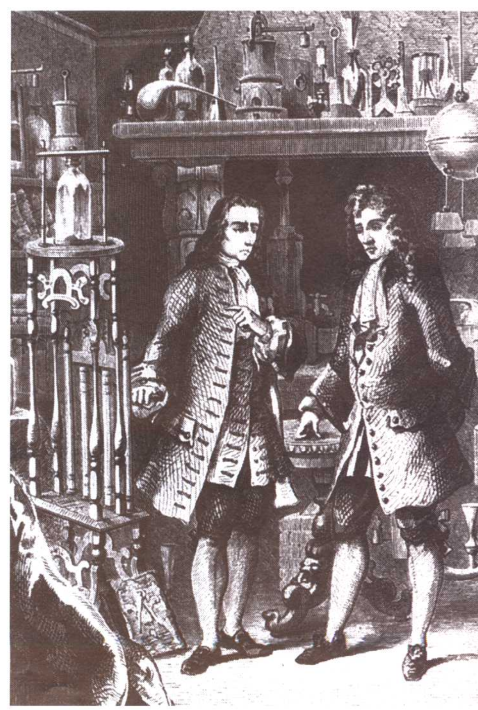
To understand a given phenomenon, these steps are repeated many times, gradually accumulating the knowledge necessary to provide a possible explanation of the phenomenon.

Once a set of hypotheses that agrees with the various observations is obtained, the hypotheses are assembled into a theory. A **theory,** which is often called a **model,** is a set of tested hypotheses that gives an overall explanation of some natural phenomenon.

It is very important to distinguish between observations and theories. An observation is something that is witnessed and can be recorded. A theory is an *interpretation*—a possible explanation of *why* nature behaves in a particular way. Theories inevitably change as more information becomes available. For example, the motions of the sun and stars have remained virtually the same over the thousands of years during which humans have been observing them, but our explanations—our theories—for these motions have changed greatly since ancient times. (See the Chemical Impact on Observations, Theories, and the Planets on page 7.)

The point is that scientists do not stop asking questions just because a given theory seems to account satisfactorily for some aspect of natural behavior. They continue doing experiments to refine or replace the existing theories. This is generally done by using the currently accepted theory to make a prediction and then performing an experiment (making a new observation) to see whether the results bear out this prediction.

Always remember that theories (models) are human inventions. They represent attempts to explain observed natural behavior in terms of human experiences. A



Robert Boyle (1627–1691) was born in Ireland. He became especially interested in experiments involving air and developed an air pump with which he produced evacuated cylinders. He used these cylinders to show that a feather and a lump of lead fall at the same rate in the absence of air resistance and that sound cannot be produced in a vacuum. His most famous experiments involved careful measurements of the volume of a gas as a function of pressure. In his book *The Skeptical Chymist,* Boyle urged that the ancient view of elements as mystical substances should be abandoned and that an element should instead be defined as anything that cannot be broken down into simpler substances. This conception was an important step in the development of modern chemistry.