

CONTENTS

PREFACE	XXVII
AUTHOR	XXIX
1. INTRODUCTION TO CHEMISTRY AND GREEN CHEMISTRY	1
1.1. IF WE DO NOT CHANGE DIRECTION	1
1.2. THE ESSENTIAL ROLE OF CHEMISTRY	2
1.3. GREEN CHEMISTRY	3
1.4. A MINI-COURSE IN CHEMISTRY	5
1.5. THE BUILDING BLOCKS OF MATTER	5
Subatomic Particles and Atoms	5
Atoms and Elements	6
The Periodic Table	7
1.6. CHEMICAL BONDS AND COMPOUNDS	8
Chemical Compounds	9
Ionic Bonds	10
Summary of Chemical Compounds and the Chemical Bond	11
Molecular Mass	11
1.7. CHEMICAL REACTIONS AND EQUATIONS	12
1.8. NUMBERS IN CHEMISTRY: EXPONENTIAL NOTATION	12
Addition and Subtraction of Exponential Numbers	13
Multiplication and Division of Exponential Numbers	14
1.9. SIGNIFICANT FIGURES AND UNCERTAINTIES IN NUMBERS	15
Significant Figures in Calculations	15
Rounding Numbers	17
Use of Three Significant Digits	17
1.10. MEASUREMENTS AND SYSTEMS OF MEASUREMENT	18
SI Units of Measurement	18
Multiples of Units	18
Metric and English Systems of Measurement	18
1.11. UNITS OF MASS	20
1.12. UNITS OF LENGTH	21
1.13. UNITS OF VOLUME	22

1.14. TEMPERATURE, HEAT, AND ENERGY	23
Temperature Scales	23
Melting Point and Boiling Point	26
Heat and Energy	27
1.15. PRESSURE	27
1.16. UNITS AND THEIR USE IN CALCULATIONS	28
Unit Conversion Factors	28
CHAPTER SUMMARY	31
Answers to Chapter Summary	33
LITERATURE CITED	36
QUESTIONS AND PROBLEMS	37
2. MATTER AND MATERIALS	45
2.1. WHAT IS MATTER AND WHY DOES IT MATTER FOR SUSTAINABILITY AND GREEN CHEMISTRY?	45
2.2. CLASSIFICATION OF MATTER	46
Some General Types of Matter	47
Mixtures and Pure Substances	48
Summary of the Classification of Matter	49
2.3. QUANTITY OF MATTER: THE MOLE	49
The Mole and Avogadro's Number	50
2.4. PHYSICAL PROPERTIES OF MATTER	50
Density	51
Specific Gravity	52
Color	53
Electromagnetic Radiation and Green Chemistry	54
2.5. STATES OF MATTER	55
2.6. GASES	56
The Gas Laws	57
Gas Law Calculations	59
2.7. LIQUIDS AND SOLUTIONS	62
Evaporation and Condensation of Liquids	62
Vapor Pressure	63
Solutions	63
2.8. SOLIDS	65
2.9. THERMAL PROPERTIES	66
Melting Point	66
Boiling Point	66
Specific Heat	66
Heat of Vaporization	68
Heat of Fusion	69
Phase Change Materials in Green Technology	69
2.10. SEPARATION AND CHARACTERIZATION OF MATTER	70
Distillation	70
Separation in Waste Treatment	71
2.11. THE GREEN CHEMISTRY OF MATTER	74
CHAPTER SUMMARY	75
QUESTIONS AND PROBLEMS	81

3.	ATOMS AND ELEMENTS	87
3.1.	ATOMS AND ELEMENTS	87
3.2.	THE ATOMIC THEORY	87
	Laws That Are Explained by Dalton's Atomic Theory	87
	Small Size of Atoms	89
	Atomic Mass	90
3.3.	SUBATOMIC PARTICLES	90
3.4.	THE BASIC STRUCTURE OF THE ATOM	91
	Atomic Number, Isotopes, and Mass Number of Isotopes	91
	Electrons in Atoms	92
3.5.	DEVELOPMENT OF THE PERIODIC TABLE	93
3.6.	HYDROGEN, THE SIMPLEST ATOM	93
	Designation of Hydrogen in the Periodic Table	94
	Showing Electrons in Hydrogen Atoms and Molecules	94
	Properties of Elemental Hydrogen	94
	Production and Uses of Elemental Hydrogen	95
3.7.	HELIUM, THE FIRST ATOM WITH A FILLED ELECTRON SHELL	95
	Occurrence and Uses of Helium	96
3.8.	LITHIUM, THE FIRST ATOM WITH BOTH INNER AND OUTER ELECTRONS	97
	Uses of Lithium	97
	Lithium, a Key Material in Green Technology	99
3.9.	THE SECOND PERIOD, ELEMENTS 4–10	99
	Beryllium, Atomic Number 4	99
	Boron, Atomic Number 5	100
	Carbon, Atomic Number 6	101
	Nitrogen, Atomic Number 7	101
	Oxygen, Atomic Number 8	102
	Fluorine, Atomic Number 9	103
	Neon, Atomic Number 10	103
3.10.	ELEMENTS 11–20, AND BEYOND	104
	The Elements Beyond Calcium	106
3.11.	A MORE DETAILED LOOK AT ATOMIC STRUCTURE	107
	Electromagnetic Radiation	107
3.12.	QUANTUM AND WAVE MECHANICAL MODELS OF ELECTRONS IN ATOMS	108
	The Wave Mechanical Model of Atomic Structure	109
	Multielectron Atoms and Quantum Numbers	111
3.13.	ENERGY LEVELS OF ATOMIC ORBITALS	113
	Hund's Rule of Maximum Multiplicity	115
3.14.	SHAPES OF ATOMIC ORBITALS	116
3.15.	ELECTRON CONFIGURATION	117
3.16.	ELECTRONS IN THE FIRST 20 ELEMENTS	118
	Electron Configuration of Hydrogen	118
	Electron Configuration of Helium	119
	Electron Configurations of Elements 2–20	119
	Lithium	119
	Valence Electrons	119

Beryllium	120
Filling the $2p$ Orbitals	120
Filling the $3s$, $3p$, and $4s$ Orbitals	121
3.17. ELECTRON CONFIGURATIONS AND THE PERIODIC TABLE	122
CHAPTER SUMMARY	126
Answers to Chapter Summary	128
QUESTIONS AND PROBLEMS	131
4. CHEMICAL BONDS, MOLECULES, AND COMPOUNDS	139
4.1. CHEMICAL BONDS AND COMPOUND FORMATION	139
Chemical Bonds and Valence Electrons	140
4.2. CHEMICAL BONDING AND THE OCTET RULE	141
The Octet Rule for Some Diatomic Gases	141
The Octet Rule for Chemical Compounds	141
4.3. IONIC BONDING	142
Electron Configurations of Ions from a Single Atom	142
Sodium Chloride as an Ionic Compound	143
Energetics in Ionic Bonding	145
Energy of Ion Attraction	146
Lattice Energy	147
Ion Size	147
Formation of Some Example Ionic Compounds	149
4.4. FUNDAMENTALS OF COVALENT BONDING	150
Chemical Bonds and Energy	150
Covalent Bonding	150
4.5. COVALENT BONDS IN COMPOUNDS	152
4.6. SOME OTHER ASPECTS OF COVALENT BONDING	154
Multiple Bonds and Bond Order	154
Lengths and Strengths of Multiple Bonds	155
Electronegativity and Covalent Bonding	156
Sharing Electrons—Unequally	157
Coordinate Covalent Bonds	158
Compounds That Do Not Conform to the Octet Rule	159
Resonance Structures	160
4.7. CHEMICAL FORMULAS OF COMPOUNDS	161
What a Chemical Formula States	161
Percentage Composition from Chemical Formulas	162
Calculation of Chemical Formulas	163
Empirical Formula from Percentage Composition	164
4.8. THE NAMES OF CHEMICAL COMPOUNDS	167
Binary Molecular Compounds	167
Names of Ionic Compounds	168
4.9. ACIDS, BASES, AND SALTS	170
Acids	170
Bases	171
Salts	171
CHAPTER SUMMARY	172
Answers to Chapter Summary	173
QUESTIONS AND PROBLEMS	175

5. CHEMICAL REACTIONS, EQUATIONS, AND STOICHIOMETRY	181
5.1. THE SENTENCES OF CHEMISTRY	181
Chemical Reactions and Equations: The Sentences of the Chemical Language	181
Quantitative Calculations from Chemical Equations	182
5.2. THE INFORMATION IN A CHEMICAL EQUATION	182
Chemical Reactions	182
Expressing a Chemical Reaction as a Chemical Equation	182
Symbols Used in Chemical Equations	183
5.3. BALANCING CHEMICAL EQUATIONS	184
Balancing the Equation for the Reaction of Hydrogen Sulfide with Sulfur Dioxide	184
Some Other Examples of Balancing Equations	185
Summary of Steps in Balancing an Equation	187
5.4. WILL A REACTION OCCUR?	188
5.5. HOW FAST DOES A REACTION GO?	190
5.6. CLASSIFICATION OF CHEMICAL REACTIONS	190
5.7. QUANTITATIVE INFORMATION FROM CHEMICAL REACTIONS	193
Review of Quantitative Chemical Terms	193
Calcination of Limestone	194
5.8. WHAT IS STOICHIOMETRY AND WHY IS IT IMPORTANT?	195
The Mole Ratio Method of Stoichiometric Calculations	196
CHAPTER SUMMARY	200
Answers to Chapter Summary	202
QUESTIONS AND PROBLEMS	203
6. ACIDS, BASES, AND SALTS	209
6.1. THE IMPORTANCE OF ACIDS, BASES, AND SALTS	209
6.2. THE NATURE OF ACIDS, BASES, AND SALTS	210
Hydrogen Ion and Hydroxide Ion	210
Acids	210
Bases	211
Salts	211
Amphoteric Substances	212
Metal Ions as Acids	212
Salts That Act as Bases	213
Salts That Act as Acids	213
6.3. CONDUCTANCE OF ELECTRICITY BY ACIDS, BASES, AND SALTS IN SOLUTION	214
Electrolytes	215
6.4. DISSOCIATION OF ACIDS AND BASES IN WATER	216
6.5. THE HYDROGEN ION CONCENTRATION AND BUFFERS	218
Buffers	219
6.6. pH AND THE RELATIONSHIP BETWEEN HYDROGEN ION AND HYDROXIDE ION CONCENTRATIONS	219
Acid–Base Equilibria	221
6.7. PREPARATION OF ACIDS	222
6.8. PREPARATION OF BASES	223
6.9. PREPARATION OF SALTS	225

6.10. ACID SALTS AND BASIC SALTS	227
Acid Salts	227
Basic Salts	227
6.11. WATER OF HYDRATION	227
6.12. NAMES OF ACIDS, BASES, AND SALTS	228
Acids	228
Bases	228
Salts	229
CHAPTER SUMMARY	232
Answers to Chapter Summary	233
QUESTIONS AND PROBLEMS	236
7. SOLUTIONS AND SOLVENTS	243
7.1. WHAT ARE SOLUTIONS? WHY ARE THEY IMPORTANT?	243
Reactions in Solution	244
Solutions in Living Systems	245
Solutions in the Environment	245
Industrial Uses of Solutions	246
7.2. SOLVENTS	246
7.3. WATER—A UNIQUE SOLVENT	247
7.4. THE SOLUTION PROCESS AND SOLUBILITY	249
7.5. SOLUTION CONCENTRATIONS	251
Molar Concentration	252
Diluting Solutions	254
Molar Concentration of H ⁺ Ion and pH	255
Solubility	256
7.6. STANDARD SOLUTIONS AND TITRATIONS	257
7.7. PHYSICAL PROPERTIES OF SOLUTIONS	259
Freezing Point Depression	259
Boiling Point Elevation	259
Osmosis	259
7.8. SOLUTION EQUILIBRIA	261
Solution Equilibria	261
Solubilities of Gases	263
7.9. COLLOIDAL SUSPENSIONS	265
Kinds of Colloidal Particles	265
Colloid Stability	266
Coagulation and Flocculation of Colloidal Particles	268
CHAPTER SUMMARY	268
Answers to Chapter Summary	270
QUESTIONS AND PROBLEMS	272
8. CHEMISTRY AND ELECTRICITY	275
8.1. CHEMISTRY AND ELECTRICITY	275
8.2. OXIDATION AND REDUCTION	276
8.3. OXIDATION-REDUCTION IN SOLUTION	279
8.4. THE DRY CELL	281
8.5. STORAGE BATTERIES	283

8.6. USING ELECTRICITY TO MAKE CHEMICAL REACTIONS OCCUR	286
Electrolysis of Water: A Green Technology	286
Electrolytic Manufacture of Chemicals	288
8.7. ELECTROPLATING	289
8.8. FUEL CELLS	290
8.9. SOLAR CELLS	291
8.10. REACTION TENDENCY	292
Measurement of E^0	293
E^0 Values and Reaction Tendency	294
8.11. EFFECT OF CONCENTRATION: NERNST EQUATION	296
8.12. POTENTIOMETRY	297
8.13. CORROSION	299
CHAPTER SUMMARY	300
Answers to Chapter Summary	302
QUESTIONS AND PROBLEMS	304
9. ORGANIC CHEMISTRY	307
9.1. ORGANIC CHEMISTRY	307
Molecular Geometry in Organic Chemistry	307
9.2. HYDROCARBONS	308
Alkanes	308
Alkenes and Alkynes	314
Alkenes and <i>Cis-Trans</i> Isomerism	315
Condensed Structural Formulas	315
Aromatic Hydrocarbons	316
9.3. ORGANIC FUNCTIONAL GROUPS AND CLASSES OF ORGANIC COMPOUNDS	318
Organo-Oxygen Compounds	319
Organonitrogen Compounds	321
Organohalide Compounds	322
Organosulfur Compounds	326
Organophosphorus Compounds	328
9.4. SYNTHETIC POLYMERS	330
CHAPTER SUMMARY	332
Answers to Chapter Summary	334
SUPPLEMENTARY REFERENCES	335
QUESTIONS AND PROBLEMS	336
10. BIOLOGICAL CHEMISTRY	339
10.1. BIOCHEMISTRY	339
Biomolecules	340
10.2. BIOCHEMISTRY AND THE CELL	340
Major Cell Features	340
10.3. PROTEINS	342
Protein Structure	344
Denaturation of Proteins	346
10.4. CARBOHYDRATES	347
10.5. LIPIDS	349

10.6. ENZYMES	351
10.7. NUCLEIC ACIDS	355
Nucleic Acids in Protein Synthesis	358
Modified DNA	359
10.8. RECOMBINANT DNA AND GENETIC ENGINEERING	359
10.9. METABOLIC PROCESSES	360
Energy-Yielding Processes	360
CHAPTER SUMMARY	361
Answers to Chapter Summary	362
LITERATURE CITED	363
SUPPLEMENTARY REFERENCES	364
QUESTIONS AND PROBLEMS	364
11. WATER AND THE HYDROSPHERE	367
11.1. INTRODUCTION	367
11.2. THE FANTASTIC WATER MOLECULE AND THE UNIQUE PROPERTIES OF WATER	367
11.3. THE HYDROSPHERE	369
11.4. COMPARTMENTS OF THE HYDROSPHERE WHERE WATER OCCURS	376
Standing Bodies of Water	376
Flowing Water	378
Free-Flowing Rivers	379
Groundwater	379
11.5. AQUATIC CHEMISTRY	381
11.6. ALKALINITY AND ACIDITY	381
Alkalinity	381
Acidity	383
11.7. METAL IONS AND CALCIUM IN WATER	384
Hydrated Metal Ions as Acids	385
Calcium and Hardness	385
11.8. OXIDATION-REDUCTION	387
pE-pH Diagram	388
11.9. COMPLEXATION AND CHELATION	389
Occurrence and Importance of Chelating Agents in Water	391
Complexation by Humic Substances	391
Metals Bound as Organometallic Compounds	393
11.10. WATER INTERACTIONS WITH OTHER PHASES	393
Sediments	394
Colloids	394
11.11. AQUATIC LIFE	395
Microorganisms in Water	395
Algae	396
Fungi	396
11.12. BACTERIA	396
The Prokaryotic Bacterial Cell	397
Bacterial Growth and Metabolism	398
11.13. MICROBIALLY MEDIATED ELEMENTAL TRANSITIONS AND CYCLES	400
Microbial Transformations of Carbon	400
Microbial Transformations of Nitrogen	402

Microbial Transformations of Sulfur	404
Microbial Transformations of Phosphorus	405
Microbial Transformations of Halogens and Organohalides	405
Microbial Transformations of Iron	406

CHAPTER SUMMARY	406
Answers to Chapter Summary	408
SUPPLEMENTARY REFERENCES	411
QUESTIONS AND PROBLEMS	412

12. ENVIRONMENTAL CHEMISTRY AND POLLUTION OF THE HYDROSPHERE **417**

12.1. NATURE AND TYPES OF WATER POLLUTANTS	417
12.2. ELEMENTAL POLLUTANTS	419
12.3. HEAVY METALS	420
Cadmium	420
Lead	421
Mercury	421
12.4. METALLOIDS	423
12.5. ORGANICALLY BOUND METALS AND METALLOIDS	423
Organotin Compounds	425
12.6. INORGANIC SPECIES	426
Cyanide	427
Ammonia and Other Inorganic Pollutants	427
Asbestos in Water	428
12.7. ALGAL NUTRIENTS AND EUTROPHICATION	428
12.8. ACIDITY, ALKALINITY, AND SALINITY	430
12.9. OXYGEN, OXIDANTS, AND REDUCTANTS	432
12.10. ORGANIC POLLUTANTS	433
Sewage	433
Soaps, Detergents, and Detergent Builders	435
Biorefractory Organic Pollutants	437
Naturally Occurring Chlorinated and Brominated Compounds	438
12.11. PESTICIDES IN WATER	439
Natural Product Insecticides, Pyrethrins, and Pyrethroids	440
DDT and Organochlorine Insecticides	440
Organophosphate Insecticides	442
Carbamates	443
Herbicides	443
Byproducts of Pesticide Manufacture	447
12.12. POLYCHLORINATED BIPHENYLS	448
Biodegradation of PCBs	449
12.13. RADIONUCLIDES IN THE AQUATIC ENVIRONMENT	450
CHAPTER SUMMARY	455
Answers to Chapter Summary	457
LITERATURE CITED	459
SUPPLEMENTARY REFERENCES	460
QUESTIONS AND PROBLEMS	460

13. SUSTAINING THE HYDROSPHERE: KEEPING WATER GREEN	465
13.1. WATER TREATMENT AND WATER USE	465
Emerging Considerations in Water Treatment	466
13.2. MUNICIPAL WATER TREATMENT	467
Contamination in Water Distribution Systems	468
13.3. TREATMENT OF WATER FOR INDUSTRIAL USE	468
13.4. SEWAGE TREATMENT	470
Primary Waste Treatment	470
Secondary Waste Treatment by Biological Processes	471
Tertiary Waste Treatment	474
Physical–Chemical Treatment of Municipal Wastewater	475
13.5. INDUSTRIAL WASTEWATER TREATMENT	475
13.6. REMOVAL OF SOLIDS	477
Dissolved Air Flotation	479
13.7. REMOVAL OF CALCIUM AND OTHER METALS	480
Removal of Iron and Manganese	484
Removal of Heavy Metals	485
Arsenic Removal	486
13.8. REMOVAL OF DISSOLVED ORGANICS	486
Removal of Herbicides	488
Removal of Taste, Odor, and Color	489
Photolysis	489
Sonolysis	490
13.9. REMOVAL OF DISSOLVED INORGANICS	490
Ion Exchange	491
Phosphorus Removal	491
Nitrogen Removal	492
13.10. MEMBRANE PROCESSES AND REVERSE OSMOSIS FOR WATER PURIFICATION	493
Reverse Osmosis	494
Electrodialysis	494
13.11. SLUDGE	495
13.12. WATER DISINFECTION	497
Disease-Causing Agents Treated by Disinfection	497
Common Disinfection Agents	498
Disinfection with Chlorine and Chloramines	498
Chlorine Dioxide	500
Ozone	500
Disinfection by Filtration	502
Miscellaneous Disinfection Agents	502
13.13. NATURAL WATER PURIFICATION PROCESSES	502
Industrial Wastewater Treatment by Soil	503
13.14. WATER—THE GREENEST MATERIAL: REUSE AND RECYCLING	504
13.15. WATER CONSERVATION	507
CHAPTER SUMMARY	508
Answers to Chapter Summary	511
SUPPLEMENTARY REFERENCES	514
QUESTIONS AND PROBLEMS	515

14. THE ATMOSPHERE: A PROTECTIVE BLANKET AROUND US	519
14.1. THE ATMOSPHERE	519
Origins of the Atmosphere	521
14.2. IMPORTANCE OF THE ATMOSPHERE	522
The Atmosphere as a Reservoir of Natural Capital	523
14.3. PHYSICAL CHARACTERISTICS OF THE ATMOSPHERE	524
Atmospheric Composition	524
Variation of Pressure and Density with Altitude	526
Stratification of the Atmosphere	527
The Ionosphere	528
14.4. ENERGY TRANSFER IN THE ATMOSPHERE	530
Earth's Radiation Budget	532
14.5. ATMOSPHERIC MASS TRANSFER, METEOROLOGY, AND WEATHER	532
Atmospheric Water in Energy and Mass Transfer	534
Air Masses	535
Topographical Effects	536
Movement of Air Masses	536
Global Weather	536
Weather Fronts and Storms	538
14.6. INVERSIONS AND AIR POLLUTION	539
14.7. GLOBAL CLIMATE AND MICROCLIMATE	540
Human Modifications of Climate	541
Microclimate	541
Effects of Urbanization on Microclimate	542
14.8. ATMOSPHERIC OXYGEN	543
14.9. ATMOSPHERIC NITROGEN	546
14.10. ATMOSPHERIC WATER	547
CHAPTER SUMMARY	548
Answers to Chapter Summary	549
SUPPLEMENTARY REFERENCES	551
QUESTIONS AND PROBLEMS	552
15. ATMOSPHERIC CHEMISTRY	555
15.1. CHEMICAL AND PHOTOCHEMICAL REACTIONS IN THE ATMOSPHERE	555
Photochemical Processes	556
15.2. FREE RADICALS	559
Hydroxyl and Hydroperoxyl Radicals in the Atmosphere	560
15.3. ACID-BASE REACTIONS IN THE ATMOSPHERE	561
Ammonia in the Atmosphere	562
15.4. INORGANIC SPECIES IN THE ATMOSPHERE	563
15.5. PARTICLES IN THE ATMOSPHERE	563
Chemical Processes for Inorganic Particle Formation	564
Reactions Involving Particles	565
15.6. THE COMPOSITION OF INORGANIC PARTICLES	566
Fly Ash	567
Asbestos	568

Toxic Metals	568
Radioactive Particles	569
15.7. CARBON OXIDES	569
Carbon Monoxide	569
Fate of Atmospheric CO	570
Carbon Dioxide in the Atmosphere	570
15.8. SULFUR DIOXIDE SOURCES AND THE SULFUR CYCLE	573
Sulfur Dioxide Reactions in the Atmosphere	574
Effects of Atmospheric Sulfur Dioxide	575
15.9. NITROGEN OXIDES IN THE ATMOSPHERE	575
Atmospheric Reactions of NO _x	576
15.10. FLUORINE, CHLORINE, AND THEIR GASEOUS COMPOUNDS	576
Chlorine and Hydrogen Chloride	577
15.11. HYDROGEN SULFIDE, CARBONYL SULFIDE, AND CARBON DISULFIDE	578
15.12. ORGANICS IN THE ATMOSPHERE	579
15.13. ORGANIC COMPOUNDS FROM NATURAL SOURCES	580
15.14. POLLUTANT HYDROCARBONS	582
15.15. NONHYDROCARBON ORGANIC COMPOUNDS IN THE ATMOSPHERE	585
Aldehydes and Ketones	585
Miscellaneous Oxygen-Containing Compounds	586
Organohalides	588
Organosulfur Compounds	590
Organonitrogen Compounds	590
CHAPTER SUMMARY	591
Answers to Chapter Summary	593
SUPPLEMENTARY REFERENCES	595
QUESTIONS AND PROBLEMS	596
16. BLUE SKIES FOR A GREEN EARTH	599
16.1. PRESERVING THE ATMOSPHERE	599
16.2. EFFECTS OF PARTICLES	600
16.3. CONTROL OF PARTICLE EMISSIONS	601
Particle Removal by Sedimentation and Inertia	601
Particle Filtration	601
Scrubbers	602
Electrostatic Removal	602
Where Does It All Go?	604
16.4. CONTROL OF CARBON MONOXIDE EMISSIONS	605
16.5. CARBON DIOXIDE AND GLOBAL WARMING	605
16.6. GREEN SCIENCE AND TECHNOLOGY TO ALLEVIATE GLOBAL WARMING	608
Minimization	608
Counteracting Measures	611
Adaptation	611
16.7. REDUCING SULFUR DIOXIDE POLLUTION	613
Sulfur Dioxide Removal	613
16.8. REDUCING NITROGEN OXIDE POLLUTION	615
Harmful Effects of Nitrogen Oxides	615
Control of Nitrogen Oxides	616

16.9. ACID RAIN	616
16.10. ORGANIC AIR POLLUTION	621
16.11. CHLOROFLUOROCARBONS AND STRATOSPHERIC OZONE DEPLETION	621
The Antarctic Ozone Hole	624
The Nobel Prize in Environmental Chemistry	625
16.12. GREEN SOLUTIONS TO STRATOSPHERIC OZONE DESTRUCTION	626
16.13. PHOTOCHEMICAL SMOG	627
Smog-Forming Automotive Emissions	627
Control of Exhaust Hydrocarbons	628
16.14. THE SMOG-FORMING PROCESS	632
Chemical Reactions in Photochemical Smog Formation	632
Regeneration of NO ₂	637
Nitrate Radical	639
Reactivity of Hydrocarbons	639
16.15. HARMFUL EFFECTS OF SMOG	640
16.16. BLUE SKY AS A GREEN RESOURCE	641
CHAPTER SUMMARY	643
Answers to Chapter Summary	645
SUPPLEMENTARY REFERENCES	647
QUESTIONS AND PROBLEMS	648
17. THE GEOSPHERE AND GEOCHEMISTRY	653
17.1. THE GEOSPHERE	653
17.2. BRANCHES OF GEOLOGY	654
Environmental Geology	654
Engineering Geology	655
Economic Geology and Geospheric Resources	656
17.3. PHYSICAL FORM OF THE GEOSPHERE	657
Plate Tectonics and Continental Drift	657
Structural Geology	658
Internal and Surface Processes	660
17.4. THE NATURE OF SOLIDS IN THE GEOSPHERE	660
Structure and Properties of Minerals	660
Kinds of Minerals	661
Evaporites	661
Volcanic Sublimates	662
Igneous, Sedimentary, and Metamorphic Rocks	663
17.5. GEOCHEMISTRY	665
Physical Aspects of Weathering	665
Chemical Weathering	665
17.6. GEOSPHERE–HYDROSPHERE INTERACTIONS AND THE FORMATION OF SEDIMENTS	667
Sediments	670
Phenomena at the Land–Ocean Interface	671
Effects of Ice	672
17.7. CLAYS	673
17.8. THE GEOSPHERE–ATMOSPHERE INTERFACE	675
17.9. THE GEOSPHERE–BIOSPHERE INTERFACE	676
17.10. THE GEOSPHERE AND THE ANTHROSPHERE	677

CHAPTER SUMMARY	677
Answers to Chapter Summary	679
SUPPLEMENTARY REFERENCES	681
QUESTIONS AND PROBLEMS	683
18. SOIL, AGRICULTURE, AND FOOD PRODUCTION	687
18.1. SOIL AND AGRICULTURE	687
Agriculture	687
Pesticides and Agriculture	690
18.2. SOIL: ESSENTIAL FOR LIFE, KEY TO SUSTAINABILITY	690
What Is Soil?	691
18.3. NATURE AND COMPOSITION OF SOIL	692
Soil Horizons	693
Water and Air in Soil	695
The Inorganic Components of Soil	697
Organic Matter in Soil	698
Soil Humus	699
The Soil Solution	700
18.4. ACID-BASE AND ION-EXCHANGE REACTIONS IN SOILS	701
Production of Mineral Acid in Soil	701
Adjustment of Soil Acidity	702
Ion-Exchange Equilibria in Soil	703
18.5. MACRONUTRIENTS IN SOIL	703
18.6. NITROGEN, PHOSPHORUS, AND POTASSIUM IN SOIL	704
Nitrogen	704
Phosphorus	708
Potassium	708
18.7. MICRONUTRIENTS IN SOIL	708
18.8. FERTILIZERS	710
18.9. SOIL LOSS AND DETERIORATION	712
Shifting Cultivation: Slash-and-Burn	712
Soil Degradation	713
Factors in Soil Sustainability	713
Soil Erosion	714
Soil Sustainability and Water Resources	715
18.10. WASTES AND POLLUTANTS IN SOIL	716
Degradation of Pesticides on Soil	717
Biodegradation and the Rhizosphere	717
18.11. SAVING THE LAND	718
Soil Restoration	719
18.12. PROCESS INTENSIFICATION IN AGRICULTURE	720
18.13. SUSTAINABLE AGRICULTURAL MANAGEMENT	721
18.14. AGROFORESTRY	723
CHAPTER SUMMARY	724
Answers to Chapter Summary	726
SUPPLEMENTARY REFERENCES	729
QUESTIONS AND PROBLEMS	731

19. SUSTAINING THE GEOSPHERE	735
19.1. MANAGING THE GEOSPHERE	735
19.2. THE ANGRY EARTH	735
19.3. EARTHQUAKES	736
Secondary Effects of Earthquakes	738
Mitigating Earthquake Effects	738
19.4. VOLCANOES	738
Mitigating Effects of Volcanoes	740
19.5. VOLCANOES, AIR POLLUTION, AND THE GEOSPHERE	740
19.6. DESTRUCTIVE LAND SURFACE MOVEMENT	742
Mass Movements and Landslides	742
Subsidence	744
Expansive Soil	745
Permafrost	745
19.7. THE VULNERABLE COASTS	745
Tropical Cyclones	746
Tsunamis	747
Coastal Erosion	747
Preserving the Coastline	749
The Threat of Rising Sea Levels	749
19.8. BUILDING ON THE GEOSPHERE	750
Site Evaluation	751
Kinds of Structures on the Geosphere	751
19.9. DIGGING IN THE DIRT	753
Excavations below the Surface	754
Green Underground Storage	754
Salt Dome Storage	756
19.10. MODIFYING THE GEOSPHERE TO MANAGE WATER	757
China's Three Gorges Dam Project	760
19.11. WATER POLLUTION AND THE GEOSPHERE	760
19.12. EFFECTS OF HUMAN ACTIVITIES ON THE GEOSPHERE	761
Extraction of Geospheric Resources: Surface Mining	761
Environmental Effects of Mining and Mineral Extraction	762
19.13. WASTE DISPOSAL AND THE GEOSPHERE	763
Municipal Refuse	763
19.14. DERELICT LANDS AND BROWNFIELDS	765
19.15. EARTH AS A SOURCE OF ESSENTIAL MATERIALS	767
Deposits from Igneous Rocks and Magmatic Activity	767
Deposits from Hydrothermal Activity	768
Deposits Formed by Sedimentary or Metamorphic Processes	768
19.16. EVALUATION OF MINERAL RESOURCES	769
19.17. EXTRACTION AND MINING	770
19.18. METALS	771
19.19. NONMETAL MINERAL RESOURCES	772
19.20. HOW LONG WILL ESSENTIAL MINERALS LAST?	778
19.21. GREEN SOURCES OF MINERALS	779
Exploitation of Lower-Grade Ores	780
Remote Sources of Minerals	781

Waste Mining	781
Recycling	782
CHAPTER SUMMARY	783
Answers to Chapter Summary	785
SUPPLEMENTARY REFERENCES	788
QUESTIONS AND PROBLEMS	790
20. THE BIOSPHERE AND BIOSPHERIC RESOURCES	795
20.1. LIFE AND THE BIOSPHERE	795
20.2. ORGANISMS AND GREEN SCIENCE AND TECHNOLOGY	796
20.3. LIFE SYSTEMS	797
The Crucial Importance of Climate	799
20.4. MAINTAINING SPECIES AND POPULATIONS	800
Saving Species and Sustainability	801
Productivity, Diversity, and Resilience	803
20.5. HUMAN EFFECTS ON THE BIOSPHERE	804
Beneficial Effects of Humans on the Biosphere	805
20.6. FROM BIOMATERIALS TO PETROLEUM AND BACK AGAIN	807
20.7. TYPES OF BIOMATERIALS	808
20.8. PHOTOSYNTHESIS PRODUCTIVITY	810
20.9. BIOMATERIALS AND THEIR PROCESSING	811
20.10. BIOBASED FEEDSTOCKS	816
20.11. GLUCOSE FEEDSTOCK	817
20.12. CELLULOSE FEEDSTOCK	819
Feedstocks from Cellulose Wastes	821
20.13. LIGNIN FEEDSTOCK	822
20.14. CHEMICAL PRODUCTION BY BIOSYNTHESIS	823
Bioconversions of Synthetic Chemicals	825
<i>p</i> -Hydroxybenzoic Acid Synthesis	825
Production of δ -Cyanovalleric Acid	827
20.15. DIRECT BIOSYNTHESIS OF POLYMERS	828
20.16. GENETICALLY ENGINEERED CROPS	829
CHAPTER SUMMARY	830
Answers to Chapter Summary	832
SUPPLEMENTARY REFERENCES	834
QUESTIONS AND PROBLEMS	835
21. TOXICOLOGICAL CHEMISTRY	839
21.1. INTRODUCTION TO TOXICOLOGY AND TOXICOLOGICAL CHEMISTRY	839
Toxicology	839
Synergism, Potentiation, and Antagonism	841
21.2. DOSE-RESPONSE RELATIONSHIPS	841
21.3. RELATIVE TOXICITIES	842
Nonlethal Effects	842
21.4. REVERSIBILITY AND SENSITIVITY	844
Hypersensitivity and Hyposensitivity	844
21.5. XENOBIOTIC AND ENDOGENOUS SUBSTANCES	845

21.6. TOXICOLOGICAL CHEMISTRY	845
Toxicants in the Body	845
21.7. KINETIC PHASE AND DYNAMIC PHASE	847
Kinetic Phase	847
Dynamic Phase	848
21.8. TERATOGENESIS, MUTAGENESIS, CARCINOGENESIS, AND EFFECTS ON THE IMMUNE AND REPRODUCTIVE SYSTEMS	851
Teratogenesis	851
Mutagenesis	851
Carcinogenesis	853
Testing for Carcinogens	856
Immune System Response	857
Estrogenic Substances	857
21.9. ATSDR TOXICOLOGICAL PROFILES	857
21.10. TOXIC ELEMENTS AND ELEMENTAL FORMS	858
Heavy Metals	858
21.11. TOXIC INORGANIC COMPOUNDS	859
21.12. TOXIC ORGANOMETALLIC COMPOUNDS	861
21.13. TOXICOLOGICAL CHEMISTRY OF ORGANIC COMPOUNDS	862
Alkane Hydrocarbons	862
Alkene and Alkyne Hydrocarbons	863
Benzene and Aromatic Hydrocarbons	863
Oxygen-Containing Organic Compounds	865
Organonitrogen Compounds	868
Organohalide Compounds	870
Organosulfur Compounds	871
Organophosphorus Compounds	872
CHAPTER SUMMARY	873
Answers to Chapter Summary	875
SUPPLEMENTARY REFERENCES	879
QUESTIONS AND PROBLEMS	880
22. THE ANTHROSPHERE AND TECHNOLOGY	883
22.1. EARTH AS MADE BY HUMANS	883
22.2. CONSTRUCTS IN THE ANTHROSPHERE	884
22.3. ANTHROSPHERIC FLOWS	886
22.4. ANTHROSPHERIC CONDUITS	886
22.5. INFRASTRUCTURE	887
22.6. TRANSPORTATION	889
The Telecommuter Society	891
22.7. THE COMMUNICATIONS REVOLUTION	892
22.8. TECHNOLOGY AND ENGINEERING	895
Engineering	897
22.9. ACQUISITION OF RAW MATERIALS	900
Raw Materials	901
Materials From Earth's Crust: Mining	901
Manufactured Materials	902
22.10. AGRICULTURE—THE MOST BASIC INDUSTRY	903

22.11. INDUSTRIES	906
Classification of Industries	907
Manufacturing	908
Automation, Robotics, and Computers in Manufacturing	909
22.12. MATERIALS SCIENCE	909
Polymers	909
Ceramics	909
Composites	910
22.13. AUTOMATION	911
22.14. ROBOTICS	913
22.15. COMPUTERS AND TECHNOLOGY	915
22.16. THINKING SMALL: MICROMACHINES AND NANOTECHNOLOGY	917
Micromachines	917
Nanotechnology	918
22.17. HIGH TECH	919
CHAPTER SUMMARY	921
Answers to Chapter Summary	923
SUPPLEMENTARY REFERENCES	925
QUESTIONS AND PROBLEMS	929
23. GREEN CHEMISTRY AND INDUSTRIAL ECOLOGY	933
23.1. CHANGING THE BAD OLD WAYS	933
23.2. GREEN CHEMISTRY	934
Twelve Principles of Green Chemistry	935
23.3. REDUCTION OF RISK: HAZARD AND EXPOSURE	938
The Risks of Not Taking Risks	940
23.4. WASTE PREVENTION AND GREEN CHEMISTRY	941
23.5. GREEN CHEMISTRY AND SYNTHETIC CHEMISTRY	942
Yield and Atom Economy	943
23.6. FEEDSTOCKS	943
Biological Feedstocks	945
23.7. REAGENTS	946
23.8. STOICHIOMETRIC AND CATALYTIC REAGENTS	949
23.9. MEDIA AND SOLVENTS	950
Water, the Greenest Solvent	951
Dense-Phase Carbon Dioxide as a Solvent	952
23.10. ENHANCING REACTIONS	953
23.11. INDUSTRIAL ECOLOGY	956
23.12. THE FIVE MAJOR COMPONENTS OF AN INDUSTRIAL ECOSYSTEM	959
23.13. INDUSTRIAL METABOLISM	961
23.14. MATERIALS FLOW AND RECYCLING IN AN INDUSTRIAL ECOSYSTEM	962
23.15. THE KALUNDBORG INDUSTRIAL ECOSYSTEM	963
23.16. CONSIDERATION OF ENVIRONMENTAL IMPACTS IN INDUSTRIAL ECOLOGY	964
23.17. LIFE CYCLES: EXPANDING AND CLOSING THE MATERIALS LOOP	966
Product Stewardship	967
Embedded Utility	968
23.18. LIFE-CYCLE ASSESSMENT	969
Scoping in Life-Cycle Assessment	970

23.19. CONSUMABLE, RECYCLABLE, AND SERVICE (DURABLE) PRODUCTS	970
Desirable Characteristics of Consumables	970
Desirable Characteristics of Recyclables	971
Desirable Characteristics of Service Products	972
23.20. DESIGN FOR ENVIRONMENT	972
Products, Processes, and Facilities	973
Key Factors in Design for Environment	974
Hazardous Materials in Design for Environment	974
23.21. INHERENT SAFETY	975
Increased Safety with Smaller Size	976
CHAPTER SUMMARY	977
Answers to Chapter Summary	979
SUPPLEMENTARY REFERENCES	981
QUESTIONS AND PROBLEMS	983
24. THE ANTHROSPHERE AND WASTES	987
24.1. PRESERVING AND ENHANCING THE ANTHROSPHERE	987
24.2. REBUILDING THE INFRASTRUCTURE	988
24.3. WASTES FROM THE ANTHROSPHERE	988
History of Hazardous Substances	989
Legislation	990
24.4. CLASSIFICATION OF HAZARDOUS SUBSTANCES AND WASTES	991
Characteristics and Listed Wastes	992
Hazardous Wastes and Air and Water Pollution Control	993
24.5. SOURCES OF WASTES	993
Types of Hazardous Wastes	994
Hazardous-Waste Generators	995
24.6. FLAMMABLE AND COMBUSTIBLE SUBSTANCES	996
Combustion of Finely Divided Particles	997
Oxidizers	997
Spontaneous Ignition	997
Toxic Products of Combustion	998
24.7. REACTIVE SUBSTANCES	999
Chemical Structure and Reactivity	1000
24.8. CORROSIVE SUBSTANCES	1001
Sulfuric Acid	1002
24.9. TOXIC SUBSTANCES	1003
Toxicity Characteristic Leaching Procedure	1003
24.10. PHYSICAL FORMS AND SEGREGATION OF WASTES	1003
24.11. ENVIRONMENTAL CHEMISTRY OF HAZARDOUS WASTES	1004
24.12. TRANSPORT, EFFECTS, AND FATES OF HAZARDOUS WASTES	1006
Physical Properties of Wastes	1006
Chemical Factors	1007
Environmental Effects of Hazardous Wastes	1007
Fates of Hazardous Wastes	1008
24.13. HAZARDOUS WASTES AND THE ANTHROSPHERE	1008
24.14. HAZARDOUS WASTES IN THE GEOSPHERE	1009
24.15. HAZARDOUS WASTES IN THE HYDROSPHERE	1011
24.16. HAZARDOUS WASTES IN THE ATMOSPHERE	1014

24.17. HAZARDOUS WASTES IN THE BIOSPHERE	1016
Microbial Metabolism in Waste Degradation	1017
CHAPTER SUMMARY	1018
Answers to Chapter Summary	1021
SUPPLEMENTARY REFERENCES	1023
QUESTIONS AND PROBLEMS	1024
25. GREEN CHEMISTRY AND INDUSTRIAL ECOLOGY IN WASTE MANAGEMENT	1029
25.1. INTRODUCTION	1029
25.2. WASTE REDUCTION AND MINIMIZATION	1030
25.3. RECYCLING	1032
Examples of Recycling	1033
Waste Oil Utilization and Recovery	1033
Waste Solvent Recovery and Recycling	1034
Recovery of Water from Wastewater	1035
25.4. PHYSICAL METHODS OF WASTE TREATMENT	1036
Methods of Physical Treatment	1038
25.5. CHEMICAL TREATMENT: AN OVERVIEW	1041
Acid–Base Neutralization	1042
Chemical Precipitation	1042
Oxidation–Reduction	1044
Electrolysis	1045
Hydrolysis	1046
Chemical Extraction and Leaching	1047
Ion Exchange	1047
25.6. PHOTOLYTIC REACTIONS	1048
25.7. THERMAL TREATMENT METHODS	1048
Incineration	1049
Hazardous-Waste Fuel	1049
Incineration Systems	1050
Types of Incinerators	1051
Combustion Conditions	1051
Effectiveness of Incineration	1052
Wet Air Oxidation	1052
UV-Enhanced Wet Oxidation	1052
25.8. BIODEGRADATION OF WASTES	1053
Biodegradability	1053
Aerobic Treatment	1054
Anaerobic Treatment	1054
Reductive Dehalogenation	1054
25.9. LAND TREATMENT AND COMPOSTING	1055
Land Treatment	1055
Composting	1056
25.10. PREPARATION OF WASTES FOR DISPOSAL	1056
Immobilization	1056
Stabilization	1057
Solidification	1057
Chemical Fixation	1060

25.11. ULTIMATE DISPOSAL OF WASTES	1060
Disposal above Ground	1060
Landfill	1060
Surface Impoundment of Liquids	1061
Deep-Well Disposal of Liquids	1062
25.12. LEACHATE AND GAS EMISSIONS	1062
Leachate	1062
Hazardous-Waste Leachate Treatment	1063
Gas Emissions	1063
25.13. <i>IN SITU</i> TREATMENT	1064
<i>In situ</i> Immobilization	1064
Vapor Extraction	1065
Solidification <i>in situ</i>	1065
Detoxification <i>in situ</i>	1065
Permeable-Bed Treatment	1066
<i>In situ</i> Thermal Processes	1066
Soil Washing and Flushing	1066
CHAPTER SUMMARY	1067
Answers to Chapter Summary	1070
SUPPLEMENTARY REFERENCES	1073
QUESTIONS AND PROBLEMS	1074

26. SUSTAINABLE ENERGY: THE KEY TO EVERYTHING	1077
26.1. THE ENERGY PROBLEM	1077
26.2. NATURE OF ENERGY	1078
26.3. SOURCES OF ENERGY USED IN THE ANTHROSPHERE	1079
26.4. ENERGY DEVICES AND CONVERSIONS	1082
Fuel Cells	1086
26.5. GREEN TECHNOLOGY AND ENERGY CONVERSION EFFICIENCY	1087
26.6. ENERGY CONSERVATION AND RENEWABLE ENERGY SOURCES	1088
26.7. PETROLEUM AND NATURAL GAS	1092
26.8. COAL	1093
Coal Conversion	1093
26.9. CARBON SEQUESTRATION FOR FOSSIL FUEL UTILIZATION	1094
26.10. NUCLEAR ENERGY	1097
Nuclear Fusion	1099
26.11. GEOTHERMAL ENERGY	1100
26.12. THE SUN: AN IDEAL, RENEWABLE ENERGY SOURCE	1101
26.13. ENERGY FROM MOVING AIR AND MOVING WATER	1104
The Surprising Success of Wind Power	1104
Energy from Moving Water	1106
26.14. BIOMASS ENERGY	1107
Ethanol Fuel	1108
Biodiesel Fuel	1109
The Unrealized Potential of Lignocellulose Fuels	1110
Biogas	1113
26.15. HYDROGEN AS A MEANS TO STORE AND UTILIZE ENERGY	1114
26.16. COMBINED POWER CYCLES	1115

CHAPTER SUMMARY	1116
Answers to Chapter Summary	1118
SUPPLEMENTARY REFERENCES	1120
QUESTIONS AND PROBLEMS	1121
27. FUNDAMENTALS OF ANALYTICAL CHEMISTRY	1125
27.1. NATURE AND IMPORTANCE OF CHEMICAL ANALYSIS	1125
27.2. THE CHEMICAL ANALYSIS PROCESS	1126
27.3. MAJOR CATEGORIES OF CHEMICAL ANALYSIS	1127
27.4. ERROR AND TREATMENT OF DATA	1128
27.5. GRAVIMETRIC ANALYSIS	1130
27.6. VOLUMETRIC ANALYSIS: TITRATION	1132
27.7. SPECTROPHOTOMETRIC METHODS	1137
Absorption Spectrophotometry	1137
Atomic Absorption and Emission Analyses	1138
Atomic Emission Techniques	1140
27.8. ELECTROCHEMICAL METHODS OF ANALYSIS	1141
27.9. CHROMATOGRAPHY	1142
High-Performance Liquid Chromatography	1144
27.10. MASS SPECTROMETRY	1145
27.11. AUTOMATED ANALYSES	1145
27.12. IMMUNOASSAY SCREENING	1146
CHAPTER SUMMARY	1147
Answers to Chapter Summary	1149
SUPPLEMENTARY REFERENCES	1152
QUESTIONS AND PROBLEMS	1152
28. ENVIRONMENTAL AND XENOBIOTICS ANALYSIS	1157
28.1. INTRODUCTION TO ENVIRONMENTAL CHEMICAL ANALYSIS	1157
28.2. ANALYSIS OF WATER SAMPLES	1158
Physical Properties Measured in Water	1158
Water Sampling	1158
Water Sample Preservation	1159
28.3. CLASSICAL METHODS OF WATER ANALYSIS	1160
28.4. INSTRUMENTAL METHODS OF WATER ANALYSIS	1161
Absorption Spectrophotometry	1161
Atomic Spectrophotometric Analysis of Water	1162
Chromatographic Analysis of Water	1163
Ion Chromatography	1163
Total Organic Carbon in Water	1165
Measurement of Radioactivity in Water	1166
Biological Toxins	1166
Summary of Water Analysis Procedures	1166
28.5. ANALYSIS OF WASTES AND SOLIDS	1166
Sample Digestion	1170
Analyte Isolation for Organics Analysis	1171
Solvent Extraction	1171

Sample Preparation for Volatile Organic Compounds	1172
Sample Cleanup	1172
28.6. TOXICITY CHARACTERISTIC LEACHING PROCEDURE	1173
28.7. ATMOSPHERIC MONITORING	1176
Methods of Air-Pollutant Analysis	1177
Determination of Sulfur Dioxide	1177
Nitrogen Oxides	1179
Analysis of Oxidants	1180
Analysis of Carbon Monoxide	1181
Determination of Hydrocarbons and Organics	1182
Analysis of Particulate Matter	1182
Direct Spectrophotometric Analysis of Gaseous Air Pollutants	1184
28.8. ANALYSIS OF BIOLOGICAL MATERIALS AND XENOBIOTICS	1185
Indicators of Exposure to Xenobiotics	1186
Analysis of Metals in Biological Samples	1187
Determination of Nonmetals and Inorganic Compounds	1188
Determination of Parent Organic Compounds	1188
Measurement of Phase I and Phase II Reaction Products	1189
Mercapturates	1191
Determination of Adducts	1192
Immunological Methods of Xenobiotics Analysis	1193
CHAPTER SUMMARY	1193
Answers to Chapter Summary	1195
LITERATURE CITED	1197
SUPPLEMENTARY REFERENCES	1198
QUESTIONS AND PROBLEMS	1199
INDEX	1205