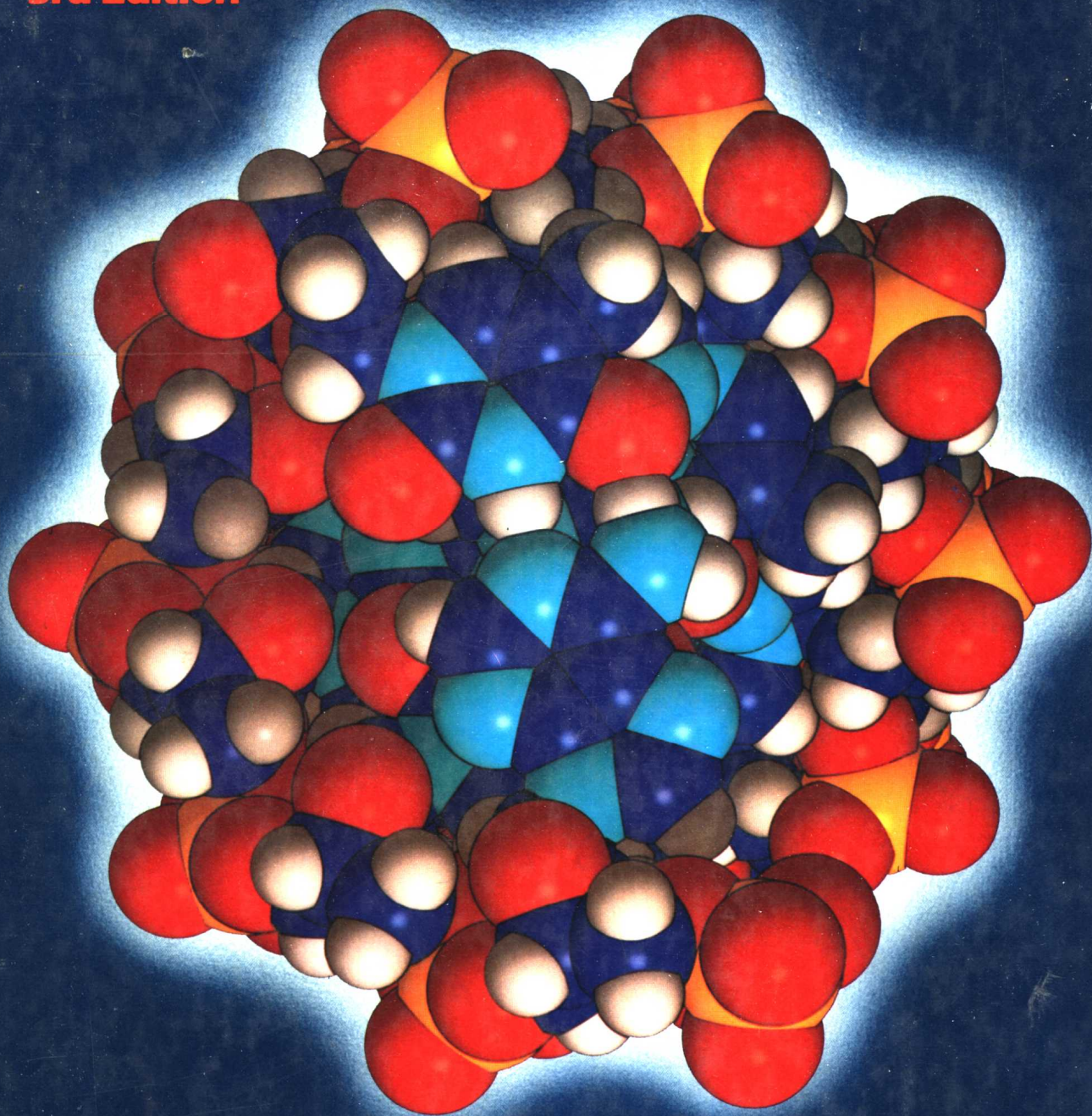


COLLEGE CHEMISTRY

An Introduction to General, Organic, and Biochemistry

H E I N / B E S T / P A T T I S O N

3rd Edition



College Chemistry

An Introduction to General, Organic, and Biochemistry

3 R D E D I T I O N

Morris Hein / Leo R. Best / Scott Pattison

Brooks/Cole Publishing Company

Monterey, California

To Edna, Louise, and Joan

Chemistry Editor: Michael V. Needham
Production Services Manager: Joan Marsh
Production: Mary Forkner, Publication Alternatives
Manuscript Editor: Yvonne Howell
Text Design: Al Burkhardt
Illustrations: Cyndie Clarke-Huegel
Typesetting: Syntax International
Cover Design: Stanley Rice
Cover Photograph: A computer generated overhead view
of a DNA molecule. Courtesy of Nelson Max, Lawrence
Livermore Laboratory.

© 1984 by Wadsworth, Inc., Belmont, California 94002.

All rights reserved. No part of this book may be reproduced, stored in a retrieval system, or transcribed, in any form or by any means—electronic, mechanical, photocopying, recording, or otherwise—without the prior written permission of the publisher, Brooks/Cole Publishing Company, Monterey, California 93940, a division of Wadsworth, Inc.

Printed in the United States of America

10 9 8 7 6 5

Library of Congress Cataloging in Publication Data

Hein, Morris.

College chemistry.

Includes index.

1. Chemistry. I. Best, Leo R. II. Pattison, Scott, 1947- . III. Title.
QD31.2.H43 1984 540 83-25284

ISBN 0-534-02863-2

Preface

As in the previous editions, the primary purpose of this third edition of *College Chemistry* is to instruct students in the basic concepts of chemistry. This book is intended for students who, although not majoring in chemistry, require a basic course in the subject including an introduction to organic chemistry and biochemistry. The text is written with the assumption that the students have not taken a previous chemistry course.

Many students are somewhat apprehensive about beginning the study of chemistry. Accordingly, one of our major goals has been to present the subject in a well-organized and readily understandable fashion. Each chapter was written with this thought in mind: Is our language clear—will the student be able to understand this material?

We believe that a fair amount of quantitative reasoning is essential to the study of chemistry. Therefore, another major goal has been to provide careful, step-by-step explanations of the topics that require quantitative reasoning. These explanations are then illustrated by one or more problems. These *example problems* are generally set up and worked by the conversion-factor dimensional analysis approach. This approach has proven to be an effective tool and requires no mathematics beyond arithmetic and elementary algebra. From experience, however, we know that to develop sufficient skill in quantitative reasoning, most students need considerable practice in working numerical problems. Consequently, we have provided many end-of-chapter problems. Fortunately, much of the time students formerly spent doing calculations by hand can now be saved by using an inexpensive electronic calculator.

In planning this revision, a nationwide survey of instructors who were users or potential users of the text provided suggestions for changes or

additions. The results of this survey indicated the need for the expanded and more effectively integrated biochemistry section found in this edition. Two additional major goals of this revision have been (1) to relate the phenomena of biochemistry to the chemical principles that are developed in the chapters on general and organic chemistry, and (2) to emphasize the central role of energy in the biochemistry of the cell.

The survey also revealed that Chapters 19–21 of the second edition dealing with metals, nonmetals, and air pollution (although generally considered to be interesting and valuable material), were the most frequently omitted in course outlines. Therefore, these three chapters were eliminated to make room for the expanded biochemistry.

The following features—some of which were developed from suggestions received from the survey—are intended to serve both as learning aids and to make the book one that students can read, understand, and study by themselves.

- A list of achievement goals is given at the beginning of each chapter as a guide to students.
- Important new terms are set in boldface type, defined in the text, and printed in the margin in color.
- Nearly all chapters have at least one self-evaluation question that contains a fairly large number of “correct” or “not correct” statements. Answers to these questions are given in Appendix V.
- A detailed discussion of scientific notation, significant figures, and rounding off numbers is given in Chapter 2. Appendix I contains a concise review of the mathematics pertinent to *College Chemistry*.
- Numerous end-of-chapter problems, mostly new or revised, are provided. These are generally arranged in order of related material within a chapter, and a few of the more challenging problems are marked with asterisks. Answers to all mathematical problems are given in Appendix V.
- The mole is used as a unifying chemical concept wherever possible.
- Material on inorganic nomenclature appears in several chapters, but for convenient reference the basic rules for naming inorganic compounds are brought together in Chapter 8.
- Examples relating to health topics are used extensively.
- The biochemical functions of various organelles are treated in the overall context of cell function.
- New chapters deal with nutrition, the cell, and bioenergetics as major topics.
- Supplementary materials that accompany *College Chemistry* are a student study guide, a laboratory manual, and a solutions manual.

It is impossible to thank by name each of the many people who have been involved and helpful in making this revision of *College Chemistry*. We are grateful for the friendship and many helpful comments and suggestions from our colleagues and students who, over the years, have made this book possible.

We are most appreciative of the critical professional reviews and suggestions by the following individuals: Gilbert Albelo, Mt. Hood Community College; Susan J. Ambo, Macomb Community College; Joseph L. Barnes, Pasadena City College; Douglas J. Bauer, Mohawk Valley Community College; Bernhard Binder, Southern Oregon State College; Arthur Breyer, Beaver College; James C. Chickos, University of Missouri, St. Louis; Phillip Dougherty, Albright College; Michael Frechette, University of Lowell, South; Karen E. Harding, Ft. Steilacoom Community College; Norbert Hepfinger, Rensselaer Polytechnic; Daniele J. Keily, Seattle Central Community College; Joseph Landesberg, Adelphi University; Paul Lauren, Suffolk County College; Robert N. Lindquist, San Francisco State University; Anthony Maniscalco, Springfield College; Clinton McPherson; Stephen Metzner, University of South Dakota; William Schultz, Eastern Kentucky University; Allan E. Smith, University of Southern Maine; Paul Whittaker, Rochester Community College; Vaughn Vandergrift, Murray State University.

No textbook can be completed without the untiring effort of many professionals in publishing. Special thanks are due to Michael V. Needham, Chemistry Editor, and Joan Marsh of Brooks/Cole Publishing Company; to Mary Forkner, production coordinator, and to Yvonne Howell, manuscript editor.

Last, but certainly not least, we are grateful to our wives, Edna, Louise, and Joan, for their patience and understanding during this revision.

Morris Hein
Leo R. Best
Scott Pattison

Contents

Preface

1	Introduction	1
1.1	The Nature of Chemistry	1
1.2	History of Chemistry	2
1.3	The Branches of Chemistry	4
1.4	Relationship of Chemistry to Other Sciences and Industry	4
1.5	Scientific Method	6
1.6	How to Study Chemistry	7
2	Standards for Measurement	9
2.1	Mass and Weight	10
2.2	Measurement and Significant Figures	10
2.3	Rounding Off Numbers	12
2.4	Scientific Notation of Numbers	13
2.5	Significant Figures in Calculations	14
2.6	The Metric System	16
2.7	Measurement of Length	18
2.8	Problem Solving	19
2.9	Measurement of Mass	22
2.10	Measurement of Volume	24

- 2.11 Heat and Temperature Scales 25
- 2.12 Heat: Quantitative Measurement 28
- 2.13 Tools for Measurement 30
- 2.14 Density 31
- 2.15 Specific Gravity 34

3 Properties of Matter 40

- 3.1 Matter Defined 40
- 3.2 Physical States of Matter 41
- 3.3 Substances and Mixtures 43
- 3.4 Properties of Substances 45
- 3.5 Physical Changes 46
- 3.6 Chemical Changes 46
- 3.7 Conservation of Mass 49
- 3.8 Energy 50
- 3.9 Energy in Chemical Changes 50
- 3.10 Conservation of Energy 51
- 3.11 Interchangeability of Matter and Energy 52

4 Elements and Compounds 55

- 4.1 Elements 55
- 4.2 Distribution of Elements 57
- 4.3 Names of the Elements 58
- 4.4 Symbols of the Elements 59
- 4.5 Compounds 60
- 4.6 Law of Definite Composition of Compounds 61
- 4.7 Chemical Formulas 62
- 4.8 Mixtures 63
- 4.9 Metals, Nonmetals, and Metalloids 64
- 4.10 Elements That Form Diatomic Molecules 65
- 4.11 Nomenclature and Chemical Equations 66

5 Atomic Theory and Structure 73

- 5.1 Early Thoughts 74
- 5.2 Dalton's Atomic Theory 74
- 5.3 Subatomic Parts of the Atom 74
- 5.4 The Nuclear Atom 76
- 5.5 General Arrangement of Subatomic Particles 78
- 5.6 The Bohr Atom 78

5.7	The Quantum Mechanical Atom	79
5.8	Energy Levels of Electrons	80
5.9	Energy Sublevels	81
5.10	Atomic Numbers of the Elements	83
5.11	The Simplest Atom: Hydrogen	84
5.12	Atomic Structures of the First Twenty Elements	84
5.13	Electron Structures of the Elements Beyond Calcium	87
5.14	Diagramming Atomic Structures	89
5.15	Electron-Dot Representation of Atoms	91
5.16	The Octet Rule	92
5.17	Isotopes of the Elements	93
5.18	Atomic Weight	94
5.19	The Mole	96

6 The Periodic Arrangement of the Elements 104

6.1	Early Attempts to Classify the Elements	105
6.2	The Periodic Law	105
6.3	Arrangement of the Periodic Table	107
6.4	Periods of Elements	110
6.5	Groups or Families of Elements	111
6.6	Predicting Formulas by Use of the Periodic Table	113
6.7	Transition Elements	115
6.8	Noble Gases	115
6.9	New Elements	116
6.10	Summary	116

7 Chemical Bonds: The Formation of Compounds from Atoms 120

7.1	Chemical Bonds	121
7.2	Ionization Energy and Electron Affinity	121
7.3	Electrons in the Outer Shell	124
7.4	The Ionic Bond: Transfer of Electrons from One Atom to Another	124
7.5	The Covalent Bond: Sharing Electrons	130
7.6	Electronegativity	132
7.7	Writing Lewis Electron-Dot Structures	133
7.8	Polar Covalent Bonds	137
7.9	Coordinate Covalent Bonds	139
7.10	Polyatomic Ions	140
7.11	Oxidation Numbers of Atoms	141

- 7.12 Oxidation Number Tables 143
7.13 Formulas of Electrovalent Compounds 144
7.14 Determining Oxidation Numbers and Ionic Charges
from a Formula 146
7.15 Oxidation-Reduction: An Introduction 148

8 Nomenclature of Inorganic Compounds 153

- 8.1 Common, or Trivial, Names 153
8.2 Systematic Chemical Nomenclature 155
8.3 Binary Compounds 155
8.4 Ternary Compounds 159
8.5 Salts with More than One Positive Ion 162
8.6 Bases 163

9 Quantitative Composition of Compounds 168

- 9.1 Formula Weight or Molecular Weight 168
9.2 Determination of Molecular Weights (Formula Weights)
from Formulas 169
9.3 Gram-Molecular Weight; Gram-Formula Weight; the Mole 170
9.4 Percentage Composition of Compounds 172
9.5 Empirical Formula versus Molecular Formula 174
9.6 Calculation of Empirical Formula 175
9.7 Calculation of the Molecular Formula from the
Empirical Formula 178

10 Chemical Equations 182

- 10.1 The Chemical Equation 182
10.2 Format for Writing Chemical Equations 183
10.3 Writing and Balancing Equations 184
10.4 What Information Does an Equation Tell Us? 188
10.5 Types of Chemical Equations 189
10.6 Heat in Chemical Reactions 194

11 Calculations from Chemical Equations 200

- 11.1 A Short Review 200
11.2 Calculations from Chemical Equations: The Mole Method 201
11.3 Mole-Mole Calculations 202
11.4 Mole-Weight and Weight-Weight Calculations 206
11.5 Limiting Reagent and Yield Calculations 208

12	The Gaseous State of Matter	215
12.1	General Properties of Gases	216
12.2	The Kinetic-Molecular Theory	216
12.3	Measurement of Pressure of Gases	219
12.4	Dependence of Pressure on Number of Molecules and Temperature	222
12.5	Boyle's Law: The Relationship of the Volume and Pressure of a Gas	224
12.6	Charles' Law: The Effect of Temperature on the Volume of a Gas	227
12.7	Standard Temperature and Pressure	231
12.8	Combined Gas Laws: Simultaneous Changes in Pressure, Volume, and Temperature	231
12.9	Dalton's Law of Partial Pressures	234
12.10	Avogadro's Hypothesis	236
12.11	Mole-Weight-Volume Relationship of Gases	237
12.12	Density and Specific Gravity of Gases	239
12.13	Calculations from Chemical Equations Involving Gases	240
12.14	Ideal Gas Equation	244
13	Water and the Properties of Liquids	250
13.1	Occurrence of Water	251
13.2	Physical Properties of Water	251
13.3	Structure of the Water Molecule	254
13.4	The Hydrogen Bond	255
13.5	Formation of Water and Chemical Properties of Water	257
13.6	Hydrates	260
13.7	Hygroscopic Substances: Deliquescence; Efflorescence	261
13.8	Hydrogen Peroxide and Ozone	262
13.9	Natural Waters	264
13.10	Water Pollution	266
13.11	Evaporation	268
13.12	Vapor Pressure	269
13.13	Boiling Point	271
13.14	Freezing Point or Melting Point	273
14	Solutions	279
14.1	Components of a Solution	280
14.2	Types of Solutions	280
14.3	General Properties of Solutions	280

14.4	Solubility	281
14.5	Factors Related to Solubility	283
14.6	Rate of Dissolving Solids	286
14.7	Solutions: A Reaction Medium	287
14.8	Concentration of Solutions	288
14.9	Colligative Properties of Solutions	300
14.10	Osmosis and Osmotic Pressure	304

15

Ionization: Acids, Bases, Salts

311

15.1	Acids and Bases	312
15.2	Reactions of Acids	314
15.3	Reactions of Bases	315
15.4	Salts	316
15.5	Electrolytes and Nonelectrolytes	317
15.6	Dissociation and Ionization of Electrolytes	318
15.7	Strong and Weak Electrolytes	320
15.8	Ionization of Water	322
15.9	Introduction to pH	323
15.10	Neutralization	328
15.11	Writing Ionic Equations	330
15.12	Colloids: An Introduction	332
15.13	Preparation of Colloids	333
15.14	Properties of Colloids	334
15.15	Stability of Colloids	335
15.16	Applications of Colloidal Properties	336

16

Chemical Equilibrium

341

16.1	Reversible Reactions	342
16.2	Rates of Reaction	343
16.3	Chemical Equilibrium	343
16.4	Principle of Le Chatelier	345
16.5	Effect of Concentration on Reaction Rate and Equilibrium	345
16.6	Effect of Pressure on Reaction Rate and Equilibrium	348
16.7	Effect of Temperature on Reaction Rate and Equilibrium	349
16.8	Effect of Catalysts on Reaction Rate and Equilibrium	351
16.9	Equilibrium Constants	351
16.10	Ionization Constants	353
16.11	Ion Product Constant for Water	356
16.12	Solubility Product Constant	358
16.13	Buffer Solutions: The Control of pH	360
16.14	Mechanism of Reactions	362

17	Oxidation – Reduction	369
17.1	Oxidation Number	369
17.2	Oxidation – Reduction	372
17.3	Balancing Oxidation – Reduction Equations	373
17.4	Balancing Ionic Redox Equations	377
17.5	Activity Series of Metals	379
17.6	Electrolytic and Voltaic Cells	382
18	Radioactivity and Nuclear Chemistry	391
18.1	Discovery of Radioactivity	392
18.2	Natural Radioactivity	393
18.3	Properties of Alpha Particles, Beta Particles, and Gamma Rays	395
18.4	Radioactive Disintegration Series	399
18.5	Transmutation of Elements	399
18.6	Artificial Radioactivity	400
18.7	Measurement of Radioactivity	401
18.8	Nuclear Fission	402
18.9	Nuclear Power	404
18.10	The Atomic Bomb	405
18.11	Nuclear Fusion	406
18.12	Mass – Energy Relationship in Nuclear Reactions	407
18.13	Transuranium Elements	408
18.14	Biological Effects of Radiation	409
18.15	Applications of Radioisotopes	410
19	Organic Chemistry: Saturated Hydrocarbons	416
19.1	Organic Chemistry: History and Scope	416
19.2	The Need for Classification of Organic Compounds	418
19.3	The Carbon Atom: Tetrahedral Structure	418
19.4	Carbon – Carbon Bonds	419
19.5	Hydrocarbons	420
19.6	Saturated Hydrocarbons: Alkanes	420
19.7	Carbon Bonding in Alkanes	421
19.8	Structural Formulas and Isomerism	423
19.9	Naming Organic Compounds	427
19.10	Reactions of Alkanes	432
19.11	Sources of Alkane Hydrocarbons	435
19.12	Octane Rating of Gasoline	435
19.13	Cycloalkanes	436

20	Unsaturated Hydrocarbons: Alkenes, Alkynes, and Aromatic Hydrocarbons	441
20.1	Alkenes and Alkynes	442
20.2	Bond Formation in Alkenes and Alkynes	443
20.3	Naming Alkenes and Alkynes	446
20.4	Geometric Isomerism	448
20.5	Cycloalkenes	452
20.6	Reactions of Alkenes	452
20.7	Acetylenes: Preparation and Properties	456
20.8	Aromatic Hydrocarbons: Structure	458
20.9	Naming Aromatic Compounds	461
20.10	Fused Aromatic Rings	465
20.11	Sources and Properties of Aromatic Hydrocarbons	466
20.12	Reactions of Aromatic Hydrocarbons	467
21	Alcohols, Phenols, and Ethers	472
21.1	Functional Groups	473
21.2	Classification of Alcohols	475
21.3	Naming Alcohols	477
21.4	Physical Properties of Alcohols	478
21.5	Reactions of Alcohols	480
21.6	Preparation and Properties of Common Alcohols	485
21.7	Phenols	488
21.8	Selected Phenolic Compounds	489
21.9	Properties of Phenols	491
21.10	Production of Phenol	491
21.11	Ethers	492
21.12	Structures and Properties of Ethers	493
21.13	Preparation of Ethers	495
21.14	Ether as an Anesthetic	495
22	Aldehydes and Ketones	500
22.1	Structure of Aldehydes and Ketones	501
22.2	Naming Aldehydes and Ketones	501
22.3	Bonding and Physical Properties	504
22.4	Reactions of Aldehydes and Ketones	505
22.5	Preparation and Properties of Common Aldehydes and Ketones	512
22.6	Iodoform Test	514
22.7	Grignard Reactions	515

23	Carboxylic Acids, Their Derivatives, and Amines	521
23.1	Carboxylic Acids	522
23.2	Nomenclature and Sources of Aliphatic Carboxylic Acids	523
23.3	Physical Properties of Carboxylic Acids	525
23.4	Classification of Carboxylic Acids	526
23.5	Preparation of Carboxylic Acids	529
23.6	Reactions of Carboxylic Acids	531
23.7	Esters	534
23.8	Glycerol Esters	538
23.9	Soaps and Synthetic Detergents	541
23.10	Amines	545
24	Polymers: Macromolecules	556
24.1	Introduction	556
24.2	Synthetic Polymers	557
24.3	Polymer Types	558
24.4	Addition Polymerization	558
24.5	Butadiene Polymers	560
24.6	Geometric Isomerism in Polymers	562
24.7	Condensation Polymers	563
24.8	Silicone Polymers	566
25	Stereoisomerism	570
25.1	Review of Isomerism	570
25.2	Plane-Polarized Light	571
25.3	Optical Activity	573
25.4	Projection Formulas	574
25.5	Enantiomers	576
25.6	Racemic Mixtures	581
25.7	Diastereomers and Meso Compounds	582
26	Carbohydrates	588
26.1	Introduction	589
26.2	Classification	591
26.3	Monosaccharides	593
26.4	Structure of Glucose and Other Aldoses	595
26.5	Cyclic Structure of Glucose; Mutarotation	597
26.6	Hemiacetals and Acetals	599

26.7	Structures of Galactose and Fructose	601	
26.8	Pentoses	602	
26.9	Disaccharides	603	
26.10	Structures and Properties of Disaccharides	603	
26.11	Reducing Sugars	606	
26.12	Reactions of Monosaccharides	608	
26.13	Polysaccharides	611	
27	Lipids		617
27.1	Classification of Lipids	617	
27.2	Simple Lipids	619	
27.3	Compound Lipids	622	
27.4	Steroids	626	
27.5	Biological Membranes	629	
28	Amino Acids, Polypeptides, and Proteins		634
28.1	Introduction	635	
28.2	The Nature of Amino Acids	636	
28.3	Essential Amino Acids	638	
28.4	D-Amino Acids and L-Amino Acids	639	
28.5	Amphoterism	639	
28.6	Formation of Polypeptides	641	
28.7	Protein Structure	644	
28.8	Enzymes	651	
28.9	Hydrolysis of Proteins	655	
28.10	Denaturation of Proteins	656	
28.11	Tests for Proteins and Amino Acids	658	
28.12	Determination of the Primary Structure of Polypeptides	659	
28.13	Synthesis of Peptides and Proteins	661	
29	Nucleic Acids and Heredity		666
29.1	Introduction	667	
29.2	Nucleosides	667	
29.3	Nucleotides: Phosphate Esters	669	
29.4	High-Energy Nucleotides	670	
29.5	Polynucleotides; Nucleic Acids	671	
29.6	Structure of DNA	671	
29.7	DNA: The Genetic Substance	675	
29.8	The Genetic Code	677	

- 29.9 Genetic Transcription, RNA 679
- 29.10 Biosynthesis of Proteins 681
- 29.11 Mutations 683
- 29.12 Genetic Engineering 686

30 Cell Structure, Body Fluids, and Respiration 689

- 30.1 Introduction 690
- 30.2 Cell Classification 691
- 30.3 Cell Membranes and Cell Walls 692
- 30.4 Subcellular Organelles 694
- 30.5 Extracellular Fluids 697
- 30.6 Oxygen/Carbon Dioxide Exchange 698
- 30.7 Nutrient Supply and Waste Removal 701
- 30.8 Hydrogen Ion Production 701
- 30.9 Water/Electrolyte Balance 702

31 Nutrition and Digestion 704

- 31.1 Introduction 705
- 31.2 Diet 705
- 31.3 Carbohydrates in the Diet 708
- 31.4 Fats in the Diet 709
- 31.5 Proteins in the Diet 710
- 31.6 Vitamins 711
- 31.7 Minerals 713
- 31.8 Water 715
- 31.9 A Balanced Diet 715
- 31.10 Human Digestion 716
- 31.11 Absorption 720
- 31.12 Liver Function 721

32 Bioenergetics 724

- 32.1 Introduction 724
- 32.2 Metabolism 725
- 32.3 Biochemical Energy Sources 725
- 32.4 Biological Oxidation-Reduction 726
- 32.5 High-Energy Phosphate Bonds 727
- 32.6 Biological Energy Transformations 730
- 32.7 Photosynthesis 733