

*Gershon J. Shugar • Jack T. Ballinger*

---

# CHEMICAL TECHNICIANS'

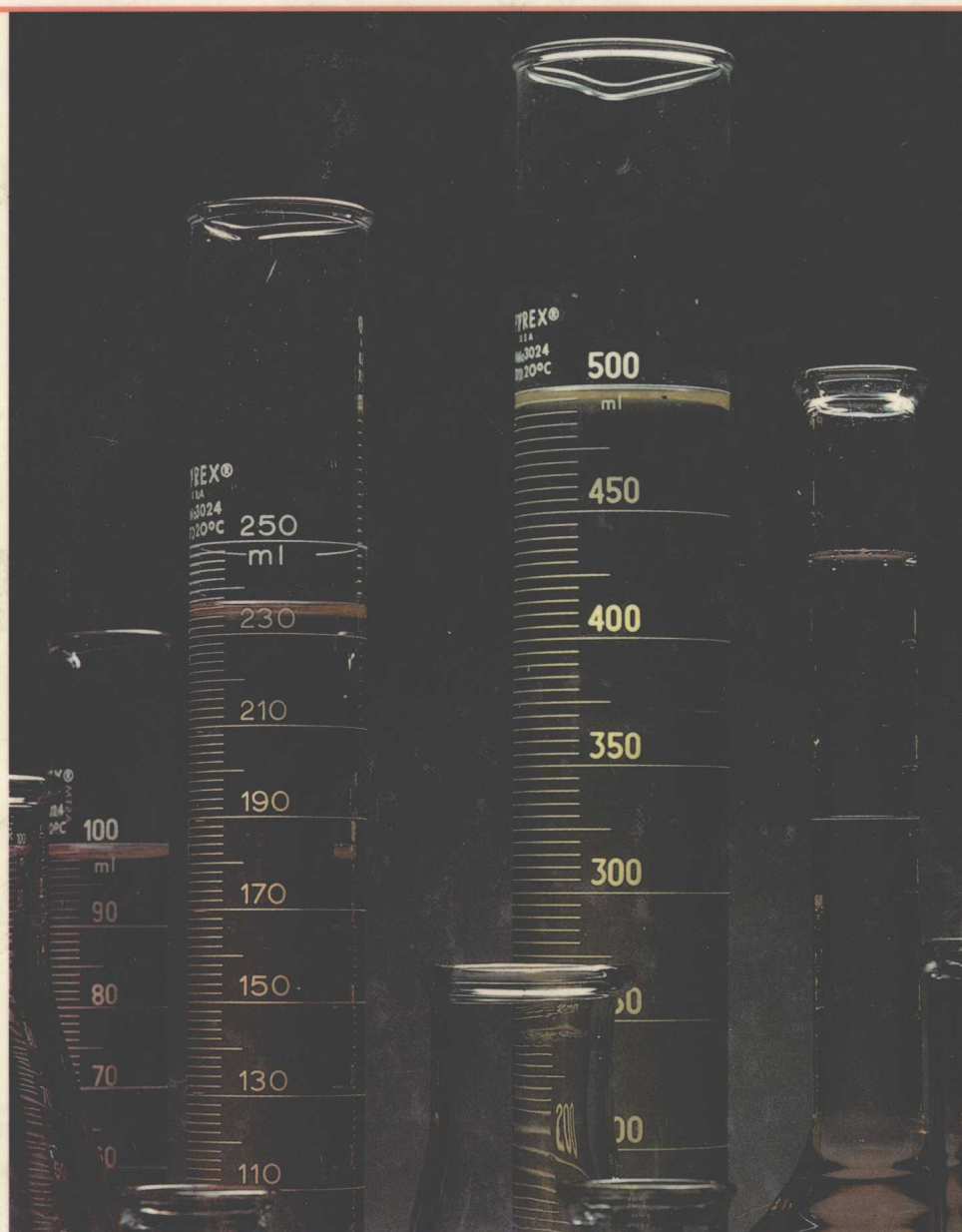
---

## READY REFERENCE

---

### HANDBOOK *Third Edition*

---



---

# CHEMICAL TECHNICIANS' READY REFERENCE HANDBOOK

---

化工技术員  
常用參考手冊

---

**Third Edition**

---

**GERSHON J. SHUGAR, B.S., M.A., Ph.D.**

*Professor, Essex County College  
Newark, New Jersey*

**JACK T. BALLINGER, B.S., M.S.**

*Professor, St. Louis Community College at Florissant Valley  
St. Louis, Missouri*

## **Consulting Editors**

**RONALD A. SHUGAR, B.S., M.D.**

*Medical Associates  
Edison, New Jersey*

**LAWRENCE BAUMAN, B.S., D.D.S.**

*Former Professor, NYU School of Dentistry  
Fanwood, New Jersey*

**ROSE SHUGAR BAUMAN, B.S.**

*Science Writer  
Watchung, New Jersey*

---

## **McGraw-Hill, Inc.**

*New York St. Louis San Francisco Auckland Bogotá  
Caracas Hamburg Lisbon London Madrid  
Mexico Milan Montreal New Delhi Paris  
San Juan São Paulo Singapore  
Sydney Tokyo Toronto*

---

Library of Congress Cataloging-in-Publication Data

Shugar, Gershon J., date

Chemical technicians' ready reference handbook/Gershon J. Shugar, Jack T. Ballinger; consulting editors, Ronald A. Shugar, Lawrence Bauman, Rose Shugar Bauman.—3rd ed.

p. cm.

Updated ed. of: Chemical technicians' ready reference handbook/Gershon J. Shugar . . . [et al.]. 2nd ed. c1981.

ISBN 0-07-057183-X

1. Chemistry—Manipulation—Handbooks, manuals, etc.

I. Ballinger, Jack T. II. Chemical technicians' ready reference handbook. III. Title.

QD61.S58 1990

542—dc20

89-43670

CIP

Copyright © 1990 by McGraw-Hill, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

234567890 DOH/DOH 9876543210

**ISBN 0-07-057183-X**

*The sponsoring editor for this book was Gail F. Nalven, the editing supervisor was Susan Thomas, the designer was Elliot Epstein, and the production supervisor was Suzanne W. Babeuf. It was set in Caledonia by University Graphics, Inc.*

*Printed and bound by R. R. Donnelley & Sons/Harrisonburg.*

Information contained in this work has been obtained by McGraw-Hill, Inc., from sources believed to be reliable. However, neither McGraw-Hill nor its authors guarantees the accuracy or completeness of any information published herein and neither McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

*For more information about other McGraw-Hill materials, call 1-800-2-MCGRAW in the United States. In other countries, call your nearest McGraw-Hill office.*

---

**CHEMICAL  
TECHNICIANS'  
READY  
REFERENCE  
HANDBOOK**

---

---

## OTHER MCGRAW-HILL BOOKS OF INTEREST

AUSTIN • *Shreve's Chemical Process Industries, 5th Edition*  
CHOPEY & HICKS • *Handbook of Chemical Engineering Calculations*  
CONSIDINE • *Process Instruments and Controls Handbook, 3d Edition*  
DEAN • *Handbook of Organic Chemistry*  
DEAN • *Lange's Handbook of Chemistry, 13th Edition*  
FREEMAN • *Hazardous Waste Minimization*  
GRANT & GRANT • *Grant & Hackh's Chemical Dictionary, 5th Edition*  
KISTER • *Distillation Operation*  
MILLER • *Flow Measurement Engineering Handbook, 2d Edition*  
NALCO • *The Nalco Water Handbook, 2d Edition*  
PERRY & GREEN • *Perry's Chemical Engineers' Handbook, 6th Edition*  
SCHWEITZER • *Handbook of Separation Techniques for Chemical Engineers, 2d Edition*  
SEYMOUR • *Engineering Polymer Sourcebook*  
SHINSKEY • *Process Control Systems, 3d Edition*  
SHUGAR & DEAN • *The Chemist's Ready Reference Handbook*

# PREFACE

---

The first and second editions of the *Chemical Technicians' Ready Reference Handbook* elicited a flood of constructive comments and suggestions from the scientific community. Many of these letters suggested the inclusion of more instrumental analysis and calibration information especially aimed at the practicing chemist and/or chemical laboratory technician. We have added comprehensive chapters on gas chromatography (GC), high-performance liquid chromatography (HPLC), infrared spectroscopy (IR), atomic absorption spectroscopy (AA), and an introduction to nuclear magnetic resonance spectroscopy (NMR).

Many letters requested additional easy-to-understand information on laboratory safety: chemical-waste disposal, material safety data sheets (MSDS), National Fire Protection Association (NFPA) codes, Right-to-Know regulations, etc. Several sections have been included in this third edition in response to the scientific community's laboratory safety concerns and responsibilities.

As was the original purpose of the Handbook, this third edition is designed to be an "omnibook" for all chemical laboratory personnel and students ranging from high school to graduate school. The Handbook is designed to give "every single step" to be followed in most of the conventional laboratory procedures. It provides a refresher guide for the professionally trained chemical technician, chemist, chemical engineer, and laboratory supervisor. Special sections including basic laboratory mathematics, introduction to statistics, organic nomenclature, and a glossary of relevant terms have been expanded to meet today's laboratory needs.

Jack T. Ballinger  
Gershon J. Shugar

# ACKNOWLEDGMENTS

---

The authors have several individuals to acknowledge and thank for their substantial contributions toward the completion of this Handbook. We are indebted to Mr. Kenneth Chapman at the American Chemical Society for his suggestion and coordination of getting the writing team of Shugar and Ballinger together. Kenneth Chapman has been involved in chemical education and training for almost twenty-five years and is still recognized as “the authority” in chemical technology training.

The authors wish to give a special thanks to the original authors (Ronald A. Shugar, Lawrence Bauman, and Rose Shugar Bauman) involved in the first and second editions of this handbook; without their efforts this Handbook would not have been possible. We would also like to thank Gail Nalven and Susan Thomas at McGraw-Hill Book Company for their guidance and assistance in the production of this rather voluminous manuscript. We would also like to thank Harold Crawford, Editor in Chief—Handbooks and Technical Books, at McGraw-Hill Book Company for his recognition of the continued need for the third edition of this updated and expanded chemical technology resource.

The following companies, publishers, and organizations have contributed to this reference book:

Ace Scientific Supply Company  
1420 East Linden Avenue  
Linden, New Jersey 07036  
Nate Schurer, Director of Marketing

Central Scientific Company  
Chicago, Illinois 60623

Fisher Scientific Company  
711 Forbes Avenue  
Pittsburgh, Pennsylvania 15219  
Michael J. Boyles, Director of Public Relations

Lab Safety Supply  
P.O. Box 1368  
Janesville, Wisconsin 53547-1368  
Claire A. Gorayeb, Catalog & Advertising Manager

Matheson Gas Products  
30 Seaview Drive  
P.O. Box 1587  
Secaucus, New Jersey 07094  
Gene Brady—Manager, Advertising Services

National Fire Protection Association  
 Batterymarch Park  
 Quincy, Massachusetts 02269-9101  
 Dennis J. Berry, Associate General Counsel

Prentice Hall, Inc.  
 Harry G. Hajian and Robert L. Pecsok, authors:  
*Modern Chemical Technology*, rev. ed. vol. 6, © 1973  
 Prentice Hall Building  
 Englewood Cliffs, New Jersey 07632  
 Maria Armand, Permissions Editor

SGA Scientific Company  
 735 Broad Street  
 Bloomfield, New Jersey 07003  
 William Geyer, President

Varian Associates, Inc.  
 220 Humboldt Court  
 Sunnyvale, California 94089  
 Judith Farrell, Product Promotion Manager

Finally, we would like to thank all the laboratory technicians involved in making our lives safer, healthier, more productive, and perhaps even easier. These dedicated individuals work daily to provide us with a safer environment and better quality of life. We invite comments, criticisms, and suggestions from these technicians and their employers as well. Good luck in the laboratory.



---

# **CHEMICAL TECHNICIANS' READY REFERENCE HANDBOOK**

---

## **ABOUT THE AUTHORS**

**Gershon J. Shugar** is Professor of Engineering Technologies, Essex County College, Newark, N.J. In 1947, he founded a chemical manufacturing business which became the largest exclusive pearlescent pigment manufacturing company in the United States. In 1968, Dr. Shugar was appointed Assistant Professor of Chemistry at Rutgers University, where he taught until his appointment at Essex County College.

**Jack T. Ballinger** is Professor of Chemistry at St. Louis Community College at Florissant Valley. In 1970, he implemented for the College a chemical technology training program, which has graduated over 300 chemical technicians and has been selected as a model program by the American Chemical Society. He has had extensive experience in the chemical, petrochemical, and environmental industries.

# CONTENTS

---

<b>Preface</b>	xv
<b>Acknowledgments</b>	xvii
<b>Chapter 1 THE CHEMICAL TECHNICIAN</b>	<b>1</b>
<i>The Role of the Chemical Technician</i> , 1	
<i>The Laboratory Notebook</i> , 3	
<i>Professional Organizations for Chemical Technicians</i> , 5	
<i>Professional References and Resources</i> , 5	
<i>Professional Sources of Information</i> , 8	
<i>Occupational Safety and Health Administration</i> , 10	
<i>Material Safety Data Sheets</i> , 10	
<i>National Fire Protection Association</i> , 13	
<b>Chapter 2 LABORATORY SAFETY</b>	<b>15</b>
<i>General Laboratory Safety Rules</i> , 15	
<i>Fire Safety</i> , 21	
<i>Explosion Safety</i> , 28	
<i>Respiratory Safety</i> , 30	
<i>Miscellaneous Laboratory Safety Equipment</i> , 32	
<i>Toxic Chemicals</i> , 32	
<i>Ventilation</i> , 35	
<i>Waste-Chemical Disposal</i> , 36	
<b>Chapter 3 HANDLING CHEMICALS AND SOLUTIONS</b>	<b>41</b>
<i>Introduction</i> , 41	
<i>General Guidelines</i> , 41	
<i>Removal of Solid Materials from Glass-Stoppered Bottles</i> , 42	
<i>Pouring Liquids from Bottles</i> , 44	
<i>Pouring Liquids from Beakers or Other Containers</i> , 45	
<i>Transferring Solutions into Containers from Pipets or Medicine Droppers</i> , 46	
<i>Shaking a Test Tube</i> , 47	
<i>Mixing Solutions in a Test Tube</i> , 47	
<i>Safe Handling of Liquids</i> , 48	
<i>Use of Pumps for Transferring Liquids</i> , 53	

<b>Chapter 4 COMPRESSED GASES IN THE LABORATORY</b>	<b>57</b>
<i>Introduction, 57</i>	
<i>General Cylinder-Handling Precautions, 57</i>	
<i>Cylinder Markings, 62</i>	
<i>Cylinder Sizes, 63</i>	
<i>What to Do with Leaking Cylinders, 64</i>	
<i>Characteristics of Common Gases, 65</i>	
<i>Compressed Air in the Laboratory, 65</i>	
<i>Proper Discharge of Cylinder Contents, 66</i>	
<i>Equipment for Control and Regulation of Gases, 66</i>	
<i>Collecting and Measuring Gases, 76</i>	
<i>Drying and Humidifying Gases, 77</i>	
<i>Control of Gases Evolved in a Reaction, 79</i>	
 <b>Chapter 5 PRESSURE AND VACUUM</b>	 <b>83</b>
<i>Introduction, 83</i>	
<i>Measuring Atmospheric Pressure, 85</i>	
<i>Absolute Pressure and Gauge Pressure, 87</i>	
<i>Gas Laws, 88</i>	
<i>Pascal's Law, 89</i>	
<i>Vacuum, 90</i>	
<i>Sources of Vacuum in the Laboratory, 90</i>	
<i>The Water Aspirator, 90</i>	
<i>The Mechanical Vacuum Pump, 93</i>	
<i>The Diffusion Pump, 93</i>	
<i>Vacuum Pumps: Use, Care, and Maintenance, 95</i>	
<i>Devices to Measure Pressure or Vacuum, 107</i>	
<i>Manostats, 119</i>	
<i>Cryogenic Liquids, 122</i>	
<i>Cryogenic Handling Precautions, 123</i>	
 <b>Chapter 6 BASIC LABORATORY MATHEMATICS</b>	 <b>125</b>
<i>International System of Units (SI), 125</i>	
<i>Dimensional Analysis, 126</i>	
<i>Conversion Factors, 130</i>	
<i>Significant Figures, 130</i>	
<i>Arithmetic in the U.S. Customary System, 132</i>	
<i>Arithmetic of Decimals, 133</i>	
<i>Arithmetic of Fractions, 137</i>	
<i>Arithmetic of Percentage, 141</i>	
<i>Logarithms, 144</i>	
<i>The Scientific Calculator, 145</i>	
 <b>Chapter 7 LABORATORY STATISTICS</b>	 <b>153</b>
<i>Introduction, 153</i>	
<i>Statistical Terminology, 153</i>	

*Rejection of Laboratory Data*, 157  
*Method of Least Squares*, 158  
*Quality Control Statistics*, 158  
*References*, 159

## **Chapter 8 COMPUTERS IN THE ANALYTICAL LABORATORY** 161

*Introduction*, 161  
*Computer Components and Terminology*, 161  
*Computer Languages*, 163  
*Computer Searches*, 163  
*References*, 163

## **Chapter 9 MEASURING TEMPERATURE** 165

*Liquid Thermometers*, 165  
*Bimetallic Expansion Thermometers*, 172  
*Liquid-Filled Remote Indicating Thermometers*, 173  
*Thermistors*, 174  
*Thermocouples*, 175  
*Optical Pyrometers*, 176  
*Other Temperature Indicators: Labels, Lacquers, Crayons, Pellets, and Liquid Crystals*, 177

## **Chapter 10 HEATING AND COOLING** 179

*General Guidelines*, 179  
*Gas Burners*, 180  
*Heating Nonflammable Liquids*, 183  
*Boiling*, 185  
*Heating Organic Liquids*, 186  
*Flameless Heating Devices*, 188  
*Other Equipment Used for Heating and Drying*, 195  
*Constant-Temperature Baths*, 197  
*Cooling Baths*, 198  
*Refrigerated Coolers*, 199

## **Chapter 11 MECHANICAL AGITATION** 201

*Introduction*, 201  
*Motors for Laboratory Mixers*, 201  
*Choice of Motor Drive*, 202  
*Choice of Stirrer*, 202  
*Magnetic Mechanical Agitation*, 204  
*Bearing Assemblies*, 205  
*Ministirrers*, 206  
*Blenders*, 207  
*Pilot-Plant Agitation*, 208

<b>Chapter 12</b>	<b>LABORATORY FILTRATION</b>	213
	<i>Introduction</i> , 213	
	<i>Filtration Methods</i> , 215	
	<i>Filter Media</i> , 215	
	<i>Filtering Accessories</i> , 219	
	<i>Manipulations Associated with the Filtration Process</i> , 222	
	<i>Gravity Filtration</i> , 224	
	<i>Vacuum Filtration</i> , 228	
	<i>Gravimetric Analysis</i> , 235	
<b>Chapter 13</b>	<b>RECRYSTALLIZATION</b>	241
	<i>Introduction</i> , 241	
	<i>Requirements of the Solvent</i> , 241	
	<i>Recrystallization of a Solid</i> , 245	
	<i>Decolorization</i> , 250	
	<i>Fractional Crystallization</i> , 252	
	<i>Laboratory Use of Purification by Fractional Crystallization</i> , 253	
	<i>Noncrystallization: "Oiling" of Compounds</i> , 254	
<b>Chapter 14</b>	<b>THE BALANCE</b>	255
	<i>Introduction</i> , 255	
	<i>Measurement</i> , 256	
	<i>Definitions of Terms</i> , 256	
	<i>Errors in Determining Mass</i> , 257	
	<i>Types of Balances</i> , 258	
	<i>Choosing the Correct Balance</i> , 268	
	<i>Accessories</i> , 269	
<b>Chapter 15</b>	<b>GRAVIMETRIC ANALYSIS</b>	271
	<i>Introduction</i> , 271	
	<i>The Techniques of Representative Sampling</i> , 271	
	<i>Handling the Sample in the Laboratory</i> , 274	
	<i>Moisture in Samples</i> , 279	
	<i>Forms of Water in Solids</i> , 280	
	<i>Effects of Grinding on Moisture Content</i> , 281	
	<i>Drying Samples</i> , 282	
	<i>Drying Collected Crystals</i> , 282	
	<i>Drying Organic Solvents</i> , 287	
	<i>Freeze-Drying: Lyophilization</i> , 290	
	<i>Preparing the Sample for Final Analysis</i> , 292	
	<i>Determining Mass of Samples</i> , 301	
	<i>Microdetermination of Carbon and Hydrogen</i> , 304	
	<i>Microdetermination of Nitrogen</i> , 307	
	<i>Determination of Halogens</i> , 309	
	<i>Determination of Sulfur</i> , 311	

<b>Chapter 16</b>	<b>LABORATORY GLASSWARE</b>	313
	<i>Introduction, 313</i>	
	<i>Ground-Glass Equipment, 314</i>	
	<i>Care of Ground-Glass Surfaces, 326</i>	
	<i>Storage of Glassware, 327</i>	
	<i>Assembly of Ground-Joint Glassware, 328</i>	
	<i>Glassblowing, 330</i>	
	<i>Handling Stoppers and Stopcocks, 340</i>	
<b>Chapter 17</b>	<b>PLASTIC LABWARE</b>	343
	<i>Introduction, 343</i>	
	<i>Effects of Chemicals on Plastics, 343</i>	
	<i>Interpretation of Chemical Resistance, 343</i>	
	<i>The Chemistry of Plastics, 349</i>	
	<i>The Use and Care of Plastic Labware, 349</i>	
	<i>Tubing: Synthetic and Natural, 352</i>	
<b>Chapter 18</b>	<b>LABORATORY HARDWARE</b>	363
	<i>Corks and Rubber Stoppers, 363</i>	
	<i>Stainless Steel in the Laboratory, 368</i>	
	<i>Tools Used in the Laboratory, 369</i>	
	<i>Tubing Used in the Laboratory, 379</i>	
<b>Chapter 19</b>	<b>DETERMINATION OF PHYSICAL PROPERTIES</b>	391
	<i>Density, 391</i>	
	<i>Specific Gravity, 396</i>	
	<i>Melting Point, 399</i>	
	<i>Boiling Point, 404</i>	
	<i>Viscosity, 408</i>	
	<i>Surface Tension, 415</i>	
	<i>Optical Rotation, 419</i>	
	<i>Refractive Index, 424</i>	
	<i>Molecular-Weight Determination, 428</i>	
	<i>Changes in Thermal Energy, 440</i>	
	<i>Physical Characteristics, 447</i>	
	<i>Centrifugation, 451</i>	
<b>Chapter 20</b>	<b>EXTRACTION</b>	457
	<i>Introduction, 457</i>	
	<i>Soxhlet Extraction, 457</i>	
	<i>Extraction of a Solute Using Immiscible Solvents, 458</i>	
	<i>Extraction Procedures in the Laboratory, 461</i>	
	<i>Considerations in the Choice of a Solvent, 462</i>	
	<i>Peroxides in Ether, 463</i>	

*Recovery of the Desired Solute from the Extraction Solvent*, 465  
*Extraction by Disposable Phase Separators*, 466  
*Continuous Liquid-Liquid Extractions*, 469  
*Ultrafiltration*, 470

**Chapter 21 DISTILLATION AND EVAPORATION** 473

*Introduction*, 473  
*Simple Distillation*, 474  
*Azeotropic Distillation*, 478  
*Fractional Distillation*, 481  
*Vacuum Distillation*, 486  
*Steam Distillation*, 493  
*Refluxing*, 498  
*Molecular Stills*, 500  
*Evaporation of Liquids*, 500  
*Rotary Evaporator*, 504  
*Sublimation*, 505

**Chapter 22 FUNDAMENTALS OF CHEMISTRY** 509

*Introduction*, 509  
*Physical and Chemical Changes*, 510  
*Chemical Symbols and Fundamental Units*, 512  
*Chemical Bonding*, 512  
*Compounds*, 517  
*Nomenclature of Inorganic Compounds*, 522  
*Formation of Coordination Compounds and Complex Ions*, 528  
*Amphoterism*, 529  
*Molecular Relationships from Equations*, 530  
*Mass Relationships from Equations*, 531  
*Volume Relationships from Equations*, 532

**Chapter 23 ORGANIC CHEMISTRY NOMENCLATURE** 533

*Introduction*, 533  
*Alkanes*, 533  
*Alkenes*, 535  
*Alkynes*, 537  
*Cyclic Hydrocarbons*, 537  
*Organic Families and Their Functional Groups*, 540  
*References*, 547

**Chapter 24 CHEMICALS AND PREPARATION OF SOLUTIONS** 549

*Introduction*, 549  
*Grades of Purity of Chemicals*, 549  
*Common Hazardous Chemicals*, 550



*Water for Laboratory Use*, 568  
*Solutions*, 572  
*Colloidal Dispersions*, 575  
*Laboratory Solutions*, 577

**Chapter 25 VOLUMETRIC ANALYSIS** 605

*Introduction*, 605  
*Tools of Volumetric Analysis*, 614  
*Performing a Titration*, 622  
*Acid–Base Titrations and Calculations*, 624  
*Oxidation–Reduction Titrations and Calculations*, 625  
*Chelates and Complexometric Titrations*, 629

**Chapter 26 pH MEASUREMENT** 631

*Introduction*, 631  
*Brønsted-Lowry Theory*, 635  
*Methods for Determining pH*, 637  
*pH Titration*, 646  
*Buffer Solutions*, 653

**Chapter 27 BASIC ELECTRICITY** 659

*Introduction*, 659  
*Electricity Compared to Fluids*, 659  
*Ohm's Law*, 660  
*Power*, 662  
*Conductors*, 663  
*Alternating and Direct Current*, 665  
*Fuses and Circuit Breakers*, 667  
*Series and Parallel Circuits*, 670  
*Electric Power*, 672  
*Servicing Inoperative Devices*, 673  
*Electrical Testing Instruments: Voltmeter, Ammeter, and Multimeter*, 673  
*Safety*, 675  
*Electric Motors*, 675  
*Belts, Pulleys, and Power Transmission*, 679  
*Making Electric Connections*, 680  
*Grounding Electric Equipment*, 685  
*Electric-Circuit Elements*, 690

**Chapter 28 ELECTROCHEMISTRY** 691

*Oxidation–Reduction Reactions*, 691  
*Activity of Metals*, 693  
*Oxidation Numbers*, 695  
*Equivalent Mass in Redox Reactions*, 696  
*Indicators*, 696