INTRODUCTION TO

# ORGANIC & SECOND EDITION

BETTELHEIM AND MARCH

# INTRODUCTION TO

# ORGANIC & BIOCHEMISTRY

SECOND EDITION

Frederick A. Bettelheim Jerry March

Adelphi University



Saunders College Publishing

**Harcourt Brace College Publishers** 

Fort Worth · Philadelphia · San Diego · New York Orlando · Austin · San Antonio Toronto · Montreal · London · Sydney · Tokyo

# To our children: Adriel Bettelheim, Gale Ackerman, David March, and June Price

Copyright © 1995, 1990 by Saunders College Publishing

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Requests for permission to make copies of any part of the work should be mailed to: Permissions Department, Harcourt Brace & Company, 6277 Sea Harbor Drive, Orlando, Florida 32887-6777.

Some material in this work also appears in INTRODUCTION TO GENERAL, ORGANIC & BIOCHEMISTRY, Fourth Edition, copyright © 1995, 1991, 1988, 1984 by Saunders College Publishing, All rights reserved.

Text Typeface: Caledonia Compositor: Progressive Information Technologies Vice President; Publisher: John Vondeling Developmental Editor: Beth Rosato Managing Editor: Carol Field Project Editor: Beth Ahrens Copy Editor: Janis Moore Manager of Art and Design: Carol Bleistine Art Director: Anne Muldrow Art and Design Coordinator: Sue Kinney Cover Designer: Lou Fuiano Text Artwork: Rolin Graphics, Inc. and J & R Technical Services, Inc. Layout Artist: Julie Anderson Director of EDP: Tim Frelick Production Manager: Charlene Squibb Vice President, Marketing: Marjorie Waldron

Cover Credit: Uncompalgre National Forest, Colorado. © Willard Clay/FPG International Frontispiece: © Phillip A. Harrington/Fran Heyl Associates

Printed in the United States of America

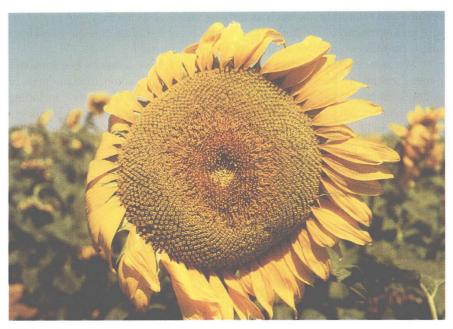
INTRODUCTION TO ORGANIC & BIOCHEMISTRY, Second Edition

0-03-001262-7

Library of Congress Catalog Card Number: 94-065432

4567890123 032 10 987654321

# PREFACE



USDA

". . . . matter is matter, neither noble nor vile, infinitely transformable, and its proximate origin is of no importance whatsoever. Nitrogen is nitrogen, it passes miraculously from the air into plants, from these into animals and from animals to us; when its function in the body is exhausted, we eliminate it, but it still remains nitrogen, aseptic, innocent" so says Primo Levi in his book *The Periodic Table*. In transforming a life-long love affair toward his chosen profession, chemistry, into literature, he succeeded in expressing his enthusiasm for all to see.

In writing the Preface for this, the second edition of our textbook, we hope that somewhat similarly we manage to convey our delight in observing the chemical processes in the core of life sciences. The increasing use of our textbook enables this new edition, and we wish to thank our colleagues who adopted previous editions for their courses. Testimony from colleagues and students indicates that we have conveyed our enthusiasm to students who find this book a great help in studying difficult concepts.

This second edition intends to be even more readable and understandable than our first edition. While maintaining the overall organization of the textbook, we strive to produce more integration of the two domains of the text organic, and biochemistry. Chemistry, especially biochemistry, is a fast-developing discipline, and we include new relevant material in the text. This is done not just by upgrading information but also by enlarging the scope of the book, both in the text and in the boxes containing medical applications of chemical principles. At the same time, we are aware of the necessity to keep the book to a manageable size and proportion. Twenty percent of the problems are new; there is an increase in the number of more challenging, thought-provoking problems (marked by asterisks).

### **AUDIENCE**

This book is intended for nonchemistry majors, mainly those entering health science and related fields (such as nursing, medical technology, physical therapy, and nutrition) or for students in environmental studies. It is intended for a one-term or a two-quarter section course in chemistry.

We assume that the students using the book have a one or two semester general chemistry background. We start by reviewing some fundamentals of general chemistry before progressing to organic and biochemistry, including acid-base chemistry. The two parts of the book are integrated by keeping a unified view of chemistry. We introduce concepts slowly at the beginning, increasing the tempo and the level of sophistication as we go on.

While teaching the chemistry of the human body is our ultimate goal, we try to show that each subsection of chemistry is important in its own right, besides being required for future understanding.

### **BOXES (Medical and Other Applications of Chemical Principles)**

The boxes contain applications of the principles discussed in the text. Comments from users of the earlier editions indicate that these are especially well received, providing a much requested relevance to the text. The large number of boxes deal mainly with health-related applications, including many also related to the environment. A list of these medically relevant applications follows the Contents. Several new boxes have been added dealing with diverse topics such as oncogenes, taxol as an anticancer agent, nitric oxide and long-term memory, sex hormones and old age, excess vitamins, rubber, and deodorants. Many boxes have been enlarged and updated. For example, boxes on Parkinson's disease, lipid storage disease, anesthetics, birth control, goiter, and AIDS now include recent material.

The presence of boxes allows a considerable degree of flexibility. If an instructor wants to assign only the main text, the boxes will not interrupt continuity and the essential material will be covered. However, most instructors will probably wish to assign at least some of the boxes, since they enhance the core material. In our experience, students are eager to read the relevant boxes even without assignments, and they do so with discrimination. From such a large number of boxes, the instructor can select those that best fit the particular needs of the course and of the students. Problems are provided for nearly all of the boxes.

### ORGANIZATION

We start by reviewing some fundamentals of general chemistry before progressing to organic and then biochemistry, including acid-base chemistry. In organic chemistry, we concentrate on the structure and properties and only the most important reactions of each class of compounds. As for the mechanisms of the reactions, we provide only one example: carbocation intermediates in addition reactions. We do this deliberately because we think that in the portion of the course devoted to organic chemistry, students do not have time to learn a

large number of reactions or anything substantial about mechanisms. As stated before, we consider the progression from organic to biochemistry an ascent. Therefore, we selected mainly organic compounds and reactions which have physiological activity of one sort or another and biological importance. In order to help students learn the reactions, we include summaries of reactions at the ends of the chapters.

Within the biochemistry chapters, we maintain the traditional order. We find this a pedagogical imperative. Even though most of the important new developments in biochemistry occur in molecular biology (Chapter 16 on Nucleic Acids and Protein Synthesis) and neurochemistry and immunology (Chapter 17 on Chemical Communication: Neurotransmitters, Hormones, and Immunoglobulins), these chapters come late in the book. We think that the appreciation of these topics requires a previous acquaintance with carbohydrate, lipid, and protein chemistry and metabolism. We hope that each instructor, to his or her taste, will judiciously appropriate time to discuss the exciting developments presented in the late chapters.

### **NEW MATERIAL**

In addition to the boxes, we include new material in the text. Some examples are

- We enlarge the discussion on cis-trans isomerism.
- We add new material on the role of chaperones in protein folding and denaturation.
- We extend the discussions on transcription factors and gene therapy.
- We describe the important polymerase-chain-reaction (PCR) technique in molecular biology.

### METABOLISM; COLOR CODE

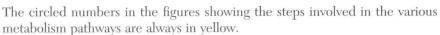
The biological functions of chemical compounds are explained in each of the biochemistry chapters and in many of the organic chapters. The emphasis is on chemistry rather than physiology. We received much positive feedback regarding the way in which we organized the topic of metabolism (Chapters 13, 14, and 15). We maintained this organization.

First, we introduce the common metabolic pathway through which all food will be utilized (citric acid cycle; oxidative phosphorylation), and only after that do we discuss the specific pathways leading to the common pathway. We find this a useful pedagogical device, and it enables us to sum up the caloric values of each type of food because their utilization through the common pathway has already been learned. Finally, we separate the catabolic pathways from the anabolic pathways by treating them in different chapters, emphasizing the different ways the body breaks down and builds up different molecules.

The topic of metabolism is a difficult one for most students. We try to explain it as clearly as possible. As in the previous edition, we enhance the clarity of presentation by the use of a color code for the most important biological compounds discussed in Chapters 13, 14, and 15. Each type of compound is

shown in a specific color, which remains the same throughout the three chapters. These colors are as follows:

ATP and other nucleoside triphosphates
ADP and other nucleoside di- and monophosphates
The oxidized coenzymes NAD+ and FAD
The reduced coenzymes NADH and FADH<sub>2</sub>
Acetyl coenzyme A



In addition to this main use of a color code, other figures in various parts of the text are color coded, so that the same color is used for the same entity throughout the text. For example, in Chapter 12, enzymes are always shown in blue and substrates in orange in all of the figures that show enzyme substrate interactions.

### **INTERVIEWS**

Each section opens with an interview with an individual who has made significant contributions in that particular field. Carl Djerassi of Stanford University is a master of steroid chemistry, both in synthesis and analyses of organic compounds, and he is often cited as the inventor of the birth control pill. Jacqueline K. Barton of the California Institute of Technology has made important discoveries relating to the structure and conformation of the DNA double helix.

These interviews are intended to give the student a human face of science and an insight of how science affects our lives.

### **FEATURES**

One of the main features of this book is the number of applications of chemical concepts presented in the boxes. Another important feature is the Glossary-Index. The definition of each term is given along with the index entry and the page number. Another feature is the list of key terms at the end of each chapter, with notation of the section number in which the term is introduced. Many students find these lists to be helpful study guides.

Other features are the summaries at the end of each chapter (including summaries of organic reactions in Chapters 3 to 8) and the substantial number of margin notes. We subsectioned the end-of-chapter problems, to guide students to the section of the chapter where they can find the relevant material.

### **STYLE**

Feedback from colleagues and students alike indicates that the style of the book, which addresses the students directly in simple and clear phrasing, is one of its major assets. We continue to make special efforts to provide clear and concise writing. Our hope is that this eases the understanding and the absorption of the difficult concepts.

### **PROBLEMS**

About one fifth of the problems are new in this edition. The number of starred problems, which contain the more challenging, thought-provoking questions, has increased. The end-of-chapter problems are grouped and subheaded in the order of topic coverage. The last group headed as Additional Problems is not arranged in any specific order. The answers to all the in-text problems and to the odd-numbered end-of-chapter problems are given at the end of the book. Answers to the even-numbered problems are included in the Instructor's Manual and the Study Guide.

### **ANCILLARIES**

This textbook is accompanied by a number of ancillary publications to help support your teaching and your students' learning:

- 1. Flash Cards by Hugh Akers (Lamar University). 200 bi-directional cards provide handy and convenient reference to the important reactions, terms, structures, and classifications of general, organic, and biological chemistry.
- 2. Study Guide by W. Scovell (Bowling Green State University). This includes review of chapter objectives, important terms and comparisons, focused review of concepts, self tests, and answers to the even-numbered problems in the text.
- 3. Instructor's Manual and Test Bank by F. A. Bettelheim and J. March. Contains suggested course outlines, exam questions chapter by chapter, answers to the exam questions, and answers to the even-numbered problems.
- 4. Computerized Test Bank available in IBM and Macintosh versions. The format permits modification of questions in the test bank and the addition of new ones.
- **5.** Approximately 160 overhead transparencies in full color. Figures and tables are taken from the text.
- 6. Laboratory Experiments for Introduction to Organic & Biochemistry, 2e by F. A. Bettelheim and J. Landesberg. Twenty-five experiments illustrate important concepts or principles in organic and biochemistry. Simple equipment and inexpensive, common, and environmentally safe chemicals are used. The large number of experiments allows sufficient flexibility for the instructor to select the usual 13 experiments the students can perform in a one-semester course.
- 7. Instructor's Manual to accompany Laboratory Experiments for *Introduction to Organic & Biochemistry*, 2e by F. A. Bettelheim and J. Landesberg. This will help instructors in grading the answers to the questions as well as in assessing the range of the experimental results obtained by the students.
- 8. Saunders Chemistry of Life Videodisc. Includes nearly all the still images from *Introduction to Organic & Biochemistry*, 2e, with large type for better classroom viewing, and contains live-action footage of chemical demonstrations.
- 9. Chemistry of Life LectureActive<sup>™</sup> Software. This outstanding, convenient package is noted for its ease of use and economy of time because all video clip and still frame data from the videodisc are entered and listed on the software. This unique program for both IBM Windows and Macintosh formats enables the instructor to swiftly access every image and film clip on the videodisc and to easily prepare a customized presentation of disc images.

### **ACKNOWLEDGMENTS**

The publication of a book such as this requires the efforts of many more people than merely the authors. A number of reviewers have read all or significant portions of the manuscript in various stages. We thank the following for their constructive criticism and helpful suggestions in revising the text for this edition:

Hugh Akers, Lamar University

Karen Eichstadt, Ohio University

Leland Harris, University of Arizona

James T. Johnson, Sinclair Community College

Margaret G. Kimble, Indiana-Purdue Universities at Fort Wayne

Kenneth E. Miller, Milwaukee Area Technical College

Thomas Pynadath, Kent State University

Guy Rosenthal, The University of Vermont

In addition, we want to acknowledge the reviewers from our previous edition of Introduction to Organic & Biochemistry:

David Jimerson, Arkansas State University

Richard Luibrand, California State University

James Paulson, University of Wisconsin

Danny V. White, American River College

Ann Willbrand, University of South Carolina

We wish to also thank reviewers of the first three editions of our longer text-book, *Introduction to General*, *Organic & Biochemistry*:

David Adams, North Shore Community College

Michael Bobrick, North Virginia Community College

Lorraine Brewer, University of Arkansas

Ana A. Ciereszko, Miami-Dade Community College South Campus

William D. Covey, Los Angeles Pierce College

Charles Cowell, Rancho Santiago College

Adrienne Curtis, Orange Coast College

Andrew Dachauer, University of San Francisco

Jane Dant, Florida Community College

Bruce Dunlap, University of South Carolina

Stanley Grenda, University of Nevada

John Griswold, Cedar Crest College

Marvin Hackert, University of Texas at Austin

Leland Harris, University of Arizona

Robert Harris, University of Nebraska

Larry Jackson, Montana State University

Eugene Kline, Tennessee Technological University

Herman Knoche, University of Nebraska

Joseph Landesberg, Adelphi University Jessie Lee, Philadelphia Community College William Masterton, University of Connecticut Melvin Merken, Worcester State College Norman Meyers, Bowling Green State University Robert Midden, Bowling Green State University Paul O'Brien, West Valley College Pat O'Day, Pasadena City College Alan Price, University of Michigan Jacqueline Scholar, Bellevue College Ronald M. Scott, Eastern Michigan University William Scovell, Bowling Green State University Brahama Sharma, Los Angeles Pierce College David Tuleen, Vanderbilt University William H. Voige, James Madison University Shan Wong, University of Lowell Albert Zabady, Montclair State College William Zuber, Memphis State University

We wish to also thank the many respondents to a survey of questions on our text and the market that Saunders commissioned for our consideration as we made plans for the new edition: Hugh Akers, Lamar University; Kim Caluo, University of Akron; Thomas Cogdell, University of Texas at Arlington; Carolyn T. Connelly, Waynesburg College; Thomas D. Crute, Augusta College; James Deavor, College of Charleston; Lawrence K. Duffy, University of Alaska, Fairbanks; Amal Girgis, Pierce College; Marie Hankins, University of Southern Indiana; Lillian M. Hansen, Tarrant County Junior College Northeast; Karen Harding, Pierce College; Chu-ngi Ho, East Tennessee State University; Vanessa Hull, Tarrant County Junior College South; Eric Johnson, Ball State University; Warren Johnson, University of Wisconsin-Green Bay; M. G. Kimble, Indiana Purdue University at Ft. Wayne; Richard Kletsch, Centralia College; M. L. Morris, North Dakota State University; Don Naschert, Illinois Central College; Mary O'Sullivan, Indiana State University; Helen Place, Washington State University; Bruce P. Ronald, Idaho State University; L. Rosenhein, Indiana State University; J. Scholar, Bellevue College; Daniel R. Tauber, Villa Julie College; Chris Vogel, Sacramento City College; Craig Weaver, Brevard Community College; Jack Wolf, El Banuaru College.

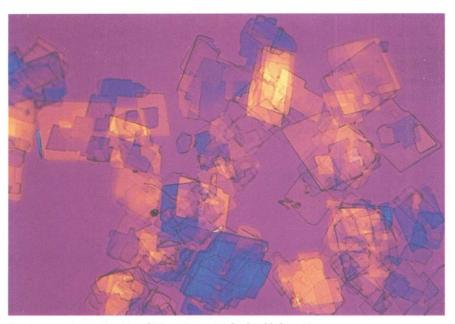
Many of our reviewers pointed out inadvertent errors or certain weaknesses in the previous edition. We attempted to correct these, and thus we hope that the second edition will prove even more useful than the first.

We also wish to thank several of our colleagues at Adelphi University for their useful advice. These include Stephen Goldberg, Joseph Landesberg, Sung Moon, Donald Opalecky, Reuben Rudman, Charles Shopsis, Kevin Terrance and Stanley Windwer. We are grateful for the support of John Vondeling, Publisher, Saunders College Publishing. We thank Beth Rosato, Developmental Editor, and Beth Ahrens, Project Editor, for their congenial steady assistance.

We would like to express our appreciation to Charlene Squibb for supervising the production of this edition and to Anne Muldrow for supervising the art. Rolin Graphics, Inc. transformed our crude drawings into pieces of art. Last but not least we want to thank Beverly March and Charles D. Winters for their many excellent photographs.

Frederick A. Bettelheim and Jerry March Adelphi University July 1994

# HEALTH-RELATED TOPICS



Drs. Dieppe, Bacon, Bamji, and Watt; Gower Medical Publishing Co.

Absorbable staples in surgery
Acidic polysaccharides in the body
Acidosis and alkalosis
Aging and racemization
AIDS
Alcoholic beverages
Alcoholism and disulfuram
Alcohols in medical use
Alkaloids
Alzheimer's disease
Amphetamines
Anabolic steroids
Anesthetics
Antacids
Anti-inflammatory drugs
Antibiotic's action
Anticancer drugs
Aspirin
Barbiturates
Bile salts
Biological effects of alkanes
Blood buffers
Blood cleansing
-1 1 1

Blood clotting

Box 7E
Sec. 9.12
Box 6E
Box 11A
Box 17I
Box 4A
2011 212
Box 4B
Sec. 4.4
Sec. 8.9
Box 17A
Box 8A
Box 10H
Box 4F
Box 6C
Box 10J
Box 16C
Box 16A
Box 7C
Boxes 8G, 13C
Sec. 10.11
Box 2B
Sec. 6.10, 18.5
Sec. 18.6
Sec. 9.12; Box 18B

Blood groups	Box 9C
Blood pressure	Sec. 18.9
Blood-brain barrier	Box 18A
Blue diaper syndrome	Box 15C
Body fluids	Box 18C
Calories	Sec. 19.3
Carbon monoxide as a poison	Box 2D
Carboxylate salts	Box 7A
Carboxylic acids	Sec. 7.4
Chaperones	Secs. 11.9-11.10
Chinese restaurant syndrome	Box 14F
Chiral compounds in the body	Sec. 9.13
Chloral hydrate	Box 5A
Cholesterol	Sec. 10.9
Cholesterol and heart attacks	Box 10G
Cis-trans isomerism in vision	Box 3C
Cocaine	Box 8I
Collagen in bones	Box 11G
Collagen abnormalities	Box 11F
Complex lipids	Secs. 10.4, 10.6–10.8
Corneal burns	Box 6B
Diabetes	Box 17G
Digestion	Secs. 19.6–19.9
	Box 14D
Diphtheria Engages in medicine	
Enzymes in medicine	Sec. 12.7
Essential amino acids	Secs. 11.2, 19.4
Essential fatty acids	Secs. 10.3, 19.4
Formalin	Sec 5.7
Fructose intolerance	Box 14A
Galactosemia	Box 9D
Gene regulation	Sec. 16.12
Genes	Sec. 16.11
Genetic diseases	Sec. 16.13
Glucose	Sec. 9.5
Glutathione	Box 11C
Glycogen storage diseases	Box 14C
Glycoproteins	Sec. 11.11
Headaches, chemically induced	Box 17E
Heavy metal poisoning	Box 12E
Hemoglobin	Box 1B
High energy phosphates	Sec. 7.12
Hormones	Sec. 17.6
Hyaline membrane disease	Box 15B
Hypertension and its control	Box 18E
Hypoglycemia and hyperglycemia	Box 19D
Iatrogenic malnutrition	Box 19A
Immunization	Box 17G
Immunoglobulins	Sec. 17.7

Insulin	Box 11D
Iodine and goiter	Box 4J
Ionic compounds in medicine	Box 1A
Jaundice	Box 14H
Ketoacidosis in diabetes	Box 14E
Ketone bodies	Sec. 14.7
Lactate accumulation	Box 14B
Leukotrienes	Sec. 10.12
Lipid storage diseases	Box 10F
Lipoproteins: HDL and LDL	Sec. 10.9
Marijuana	Box 4H
Membranes	Sec. 10.5
Menstrual cycle	Box 10I
Methanol as a poison	Box 4C
Molecular diseases	Box 16E
Monoamine oxidase inhibitors	Sec. 17.4
Multiple sclerosis	Box 10E
Muscle relaxants	Box 12A
Mutagens and carcinogens	Box 16F
Myelin sheath	Box 10E
Nerve gases	Box 17B
Neurotransmitters	Secs. 17.2-17.5
Nicotine and nicotinic acid	Box 13A
Nitric oxide and memory	Box 17F
Nitroglycerine	Box 4D
Nitrosamines as carcinogens	Box 8C
Nutrition	Chapter 19
Oncogenes	Box 16G
Oral contraception	Box 10I
Oxytocin	Sec. 11.7
Pain relievers	Box 8D
Parenteral nutrition	Box 19B
Parkinson's disease	Box 17D
Penicillin	Box 12F
pH of body fluids	Sec. 6.8
Phenols as antiseptics	Box 4E
Phenylketonuria (PKU)	Box 14G
Plastics in surgery	Sec. 3.7
Polyesters in surgery	Box 7D
Protein denaturation	Box 11H
Prostaglandins	Sec. 10.12
Recombinant DNA	Sec. 16.14
Retina detachment	
	Box 9F
Sex hormones and old age	Sec. 10.10; Box 18D
Sickle cell anemia	Box 11E
Smoking and carcinogens	Box 3F
Solubility of drugs in body	Box 8B
Steroids Sulfo drugs	Sec. 10.10
Sulfa drugs	Box 12D

### xxviii HEALTH-RELATED TOPICS

MACCO.	
Teratogen	Box 9G
Thalidomide	Box 9G
Tranquilizers	Box 8H
Urea	Box 8F
Vasopressin	Sec. 11.7
Viruses	Box 16D
Vitamins	Sec. 19.5; Box 190

# **CONTENTS OVERVIEW**



Beverly March

## Interview: Carl Djerassi

- 1 Organic Chemistry and Chemical Bonding 5
- 2 Alkanes 31
- 3 Alkenes, Alkynes, and Aromatic Compounds 63
- 4 Alcohols, Phenols, Ethers, and Halides 101
- 5 Aldehydes and Ketones 131
- 6 Acids and Bases 155
- 7 Carboxylic Acids and Esters 187
- 8 Amines and Amides 215

### Interview: Jacqueline K. Barton 245

- 9 Carbohydrates 249
- 10 Lipids 287
- 11 Proteins 317
- 12 Enzymes 343
- 13 Bioenergetics. How the Body Converts Food to Energy 361
- 14 Specific Catabolic Pathways: Carbohydrate, Lipid, and Protein Metabolism 383
- 15 Biosynthetic Pathways 407
- 16 Nucleic Acids and Protein Synthesis 419

- 17 Chemical Communication: Neurotransmitters, Hormones, and Immunoglobulins 455
- 18 Body Fluids 477
- 19 Nutrition and Digestion 495

Answers to In-Text and Odd-Numbered End-of-Chapter Problems A.1

Glossary-Index I.1