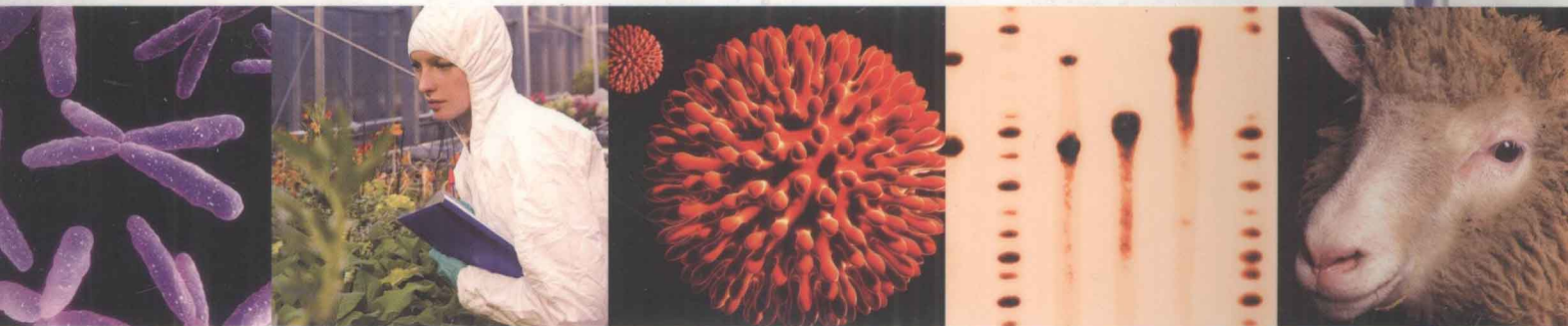


Introduction to Biotechnology

Second Edition

William J. Thieman and Michael A. Palladino



Introduction to Biotechnology

Second Edition

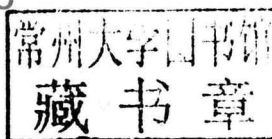


William J. Thieman

Ventura College, Emeritus

Michael A. Palladino

Monmouth University



San Francisco Boston New York

London Toronto Sydney Tokyo Singapore Madrid

Mexico City Munich Paris Cape Town Hong Kong Montreal

Editor-in-Chief: Beth Wilbur
Executive Director of Development: Deborah Gale
Acquisitions Editor: Becky Ruden
Project Editor: Leata Holloway
Managing Editor: Michael Early
Production Supervisor: Lori Newman
Production Management: Maria McColligan, Nesbitt Graphics, Inc.
Copy Editor: Anne Lesser
Compositor: Nesbitt Graphics, Inc.
Design Manager: Mark Ong
Interior Designer: Jerilyn Bockorick, Nesbitt Graphics, Inc.
Cover Designer: Rich Leeds, Big Wig Design
Illustrators: Nesbitt Graphics, Inc.
Photo Researcher: Maureen Spuhler
Director, Image Resource Center: Melinda Patelli
Image Rights and Permissions Manager: Zina Arabia
Image Permissions Coordinator: Elaine Soares
Manufacturing Buyer: Michael Penne
Executive Marketing Manager: Lauren Harp
Text printer: Edwards Brothers
Cover printer: Phoenix Color Corp.

Cover Photo Credits (from left to right): Chromosome, Sebastian Kaulitzki/Shutterstock; Scientist inspecting plants, Image Source/Veer; VIRUS, Sebastian Kaulitzki/Shutterstock; DNA image, Courtesy of Orchid Cellmark, Inc., Germantown, Maryland; Dolly, the cloned sheep, Najlah Feanny/CORBIS SABA; and Pipette background image, Caren Brinkema/Science Faction/Getty Images

Copyright ©2009 Pearson Education, Inc., publishing as Pearson Benjamin Cummings, 1301 Sansome St., San Francisco, CA 94111. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, 1900 E. Lake Ave., Glenview, IL 60025. For information regarding permissions, call (847) 486-2635.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial caps or all caps.

Pearson/Benjamin Cummings is a trademark, in the U.S. and/or other countries, of Pearson Education, Inc. or its affiliates.

Library of Congress Cataloging-in-Publication Data

Thieman, William J.

Introduction to biotechnology / William J. Thieman, Michael A. Palladino. — 2nd ed.
p.; cm.

Includes bibliographical references and index.

ISBN 978-0-321-49145-9

1. Biotechnology. I. Palladino, Michael Angelo. II. Title.

[DNLM: 1. Biotechnology. 2. Genetic Techniques. 3. Molecular Biology. TP 248.2 T433i 2009]

TP248.2.T49 2009

660.6—dc22

2008019077

ISBN 0321491459/9780321491459



PEARSON
Benjamin
Cummings

1 2 3 4 5 6 7 8 9 10—EDB—12 11 10 09 08
www.pearsonhighered.com

Introduction to **Biotechnology**

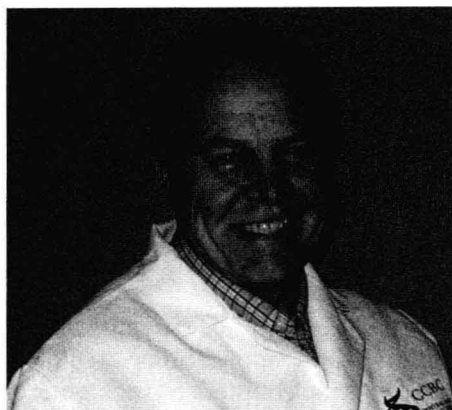
To my wife Billye, the love of my life,
and to the hundreds of biotechnology graduates
who are now doing good science at biotechnology companies
and loving every minute of it.

W. J. T.

To Maria and Angelo, my parents,
for providing all the love and support
a family could ask for.

M. A. P.

About the Authors



Mr. Bill Thieman in the lab.

William J. Thieman taught biology at Ventura College for 35 years and biotechnology for 11 years before retiring from full time teaching in 2005. He continues to teach the biotechnology course at Ventura part-time. He received his B.A. in biology from California State University at Northridge in 1966 and his M.A. degree in Zoology in 1969 at UCLA. In 1993, he started a biotechnician training program at Ventura College where he has been teaching since 1970. In 1995, he added laboratory skills components to the course and articulated it as a state-approved vocational program.

Mr. Thieman has taught a broad range of undergraduate courses including general, human, and cancer biology. He received the Outstanding Teaching Award from the National Biology Teachers Association in 1996 and the 1997 and 2000 Student Success Award from the California Community Colleges Chancellor Office. The Economic Development Association presented the biotechnology training program at Ventura College its 1998 Program for Economic Development Award for its work with local biotechnology companies. His success at acquiring grants to support the program was recognized at the National Center for Resource Development Conference in 2007.



Dr. Palladino in the lab with undergraduate biology student researchers.

Michael A. Palladino is Dean of the School of Science, Technology and Engineering, and an Associate Professor of Biology at Monmouth University in West Long Branch, New Jersey. He received his B.S. degree in Biology from Trenton State College (now known as The College of New Jersey) in 1987, and his Ph.D. in Anatomy and Cell Biology from the University of Virginia in 1994. From 1994 to 1999, he was a faculty member at Brookdale Community College in Lincroft, New Jersey. He joined the Monmouth faculty in 1999.

Dr. Palladino has taught a wide range of undergraduate courses. He has received several awards for research and teaching including the Distinguished Teacher Award from Monmouth University, Caring Heart Award from the New Jersey Association for Biomedical Research, the New Investigator Award of the American Society of Andrology, and the Outstanding Colleague Award from Brookdale Community College. At Monmouth, he has an active lab of undergraduates involved in research on the cell and molecular biology of male reproductive organs. He is founder and director for the New Jersey Biotechnology Educators Consortium, a statewide association for biotechnology teachers.

Dr. Palladino is author of *Understanding the Human Genome Project*, the first volume in the *Benjamin Cummings Special Topics in Biology Series* for which he also serves as series editor. Dr. Palladino recently joined the writing team of W.S. Klug, M.R. Cummings and C.A. Spencer on *Concepts of Genetics* and *Essentials of Genetics*, both published by Benjamin Cummings.

Preface

It is hard to imagine a more exciting time to be studying biotechnology. Advances are occurring at a dizzying pace, and biotechnology has made an impact on many aspects of our everyday lives. *Introduction to Biotechnology* is the first biotechnology textbook written specifically for the diverse backgrounds of undergraduate students. Appropriate for students at both two- and four-year schools and vocational technical schools, *Introduction to Biotechnology* provides students with the tools for practical success in the biotechnology industry through its balanced coverage of molecular biology, details on contemporary techniques and applications, integration of ethical issues, and career guidance.

Introduction to Biotechnology was designed with several major goals in mind. The text aims to provide:

- An engaging and easy-to-understand narrative that is appropriate for a diverse student audience with varying levels of scientific knowledge.
- Assistance to instructors teaching all major areas of biotechnology and help to students learning fundamental scientific concepts without overwhelming and excessive detail.
- An overview of historic applications while emphasizing modern, cutting-edge, and emerging areas of biotechnology.
- Insights on how biotechnology applications can provide some of the tools to solve important scientific and societal problems for the benefit of humankind and the environment.
- Inspiration for students to ponder the many ethical issues associated with biotechnology.

Introduction to Biotechnology provides broad coverage of topics including molecular biology, bioinformatics, genomics, and proteomics. We have strived to incorporate balanced coverage of basic molecular biology with practical and contemporary applications of biotechnology to

provide students with the tools and knowledge to understand the field.

In our effort to introduce students to the cutting-edge techniques and applications of biotechnology, we dedicated specific chapters to such emerging areas as agricultural biotechnology (Chapter 6), forensic biotechnology (Chapter 8), bioremediation (Chapter 9), and aquatic biotechnology (Chapter 10). Consideration of the many regulatory agencies and issues that impact the biotechnology industry are discussed in Chapter 12. In addition to the ethical issues included in each chapter as *You Decide* boxes, a separate chapter (Chapter 13) is dedicated to ethics and biotechnology.

Features

Introduction to Biotechnology is specifically designed to provide several key elements that will help students enjoy learning about biotechnology and prepare them for a career in biotechnology.

Learning Objectives

Each chapter begins with a short list of learning objectives that present key concepts that students should understand after studying each chapter.

Abundant Illustrations

Approximately 200 figures and photographs provide comprehensive coverage to support chapter content. Illustrations, instructional diagrams, tables, and flow charts present step-by-step explanations that visually help students learn about laboratory techniques and complex processes that are important in biotechnology.



Career Profiles

A special box at the end of each chapter introduces students to different job options and career paths in the biotechnology industry and provides detailed information on job functions, salaries, and guidance for preparing to enter the workforce. Experts currently working in the biotechnology industry have contributed information to many of these **Career Profile** boxes. We strongly encourage students to refer to these profiles if they are interested in learning more about careers in the industry.



You Decide

From genetically modified foods to stem cell research, there are an endless number of topics in biotechnology that provoke strong ethical, legal, and social questions and dilemmas. **You Decide** boxes stimulate discussion in each chapter by presenting students with information that relates to the social and ethical implications of biotechnology followed by a set of questions for them to consider. The goal of these boxes is to help them understand *how* to consider ethical issues and formulate their own informed decisions.



Tools of the Trade

Biotechnology is based on the application of various laboratory techniques or tools in molecular biology, biochemistry, bioinformatics, genetics, mathematics, engineering, computer science, chemistry, and other disciplines. **Tools of the Trade** boxes in each chapter present modern techniques and technologies related to the content of each chapter to help students learn about the techniques and laboratory methods that are the essence of biotechnology.



Question & Answer (Q&A) Boxes

Q & A boxes in each chapter present students with questions they might be wondering about as they read the book. The answers provide background information and enrich student learning.

Questions & Activities

Questions are included at the conclusion of each chapter to reinforce student understanding of concepts. Activities frequently include internet assignments that ask students to explore a cutting-edge topic. Answers to these questions are provided at the end of the text.

References and Further Reading

A short list of references at the end of each chapter is provided as a starting point for students to learn more about a particular topic in biotechnology. We have carefully chosen articles that will help students and motivate them to learn more about a subject. Typically these references include primary research papers, review articles, and articles from the popular literature.

Keeping Current: Web Links

Because biotechnology is such a rapidly changing discipline, it is virtually impossible to keep a textbook updated on new and exciting discoveries. To help students access the most current information available, a rich complement of high-quality web links to some of the best sites in biotechnology and related disciplines are available on the Companion Website for this text, www.pearsonhighered.com/biotechnology. Realizing that web links may frequently change, we tried to select substantive sites that are well established. We encourage you to let us know when you encounter address changes so we may update them.

Glossary

Like any technical discipline, biotechnology has a lexicon of terms and definitions that are routinely used when discussing processes, concepts, and applications. The most important terms are shown in **boldface type** throughout the book and are defined as they appear in the text. Definitions of these key terms are included in a glossary at the end of the book.

New Features for the Second Edition

The second edition of *Introduction to Biotechnology* includes several new instructor resources and exciting features:

- Increased end-of-chapter Questions and Activities, including more Internet-based exercises.
- A computerized test bank with multiple choice questions for each chapter; electronic files for all images in the textbook; and PowerPoint Lecture Outline slides, conveniently located on the Instructor's Resource Center, www.pearsonhighered.com/educator.
- New *You Decide* entries have been added to stimulate student interest in controversial areas of biotechnology.

In addition, each chapter has been thoroughly revised and updated to provide students with current information on emerging areas of biotechnology. Of special note are the following changes:

- **Chapter 1: The Biotechnology Century and Its Workforce** includes a new section on the "Business of Biotechnology" describing biotech company organization and structure, top biotechnology and pharmaceutical companies, and updated data on the biotechnology industry worldwide.
- **Chapter 2: An Introduction to Genes and Genomes** provides new content on transcription factors.
- **Chapter 3: Recombinant DNA Technology and Genomics** includes new sections on RNA interference (RNAi) and genomics and bioinformatics, updated content on the Human Genome Project, new content on comparative genomics, stone age genomics, and the "omics" revolution, and new content on high-throughput computer automated DNA sequencing, and real-time PCR.
- **Chapter 4: Proteins as Products** includes new information on mass spectrometry as the method of choice for protein sequencing and protein identification, and protein microarray studies.
- **Chapter 5: Microbial Biotechnology** includes new information on potential biological pathogens for bioweapons attacks on food sources, the use of gene microarrays for detecting host responses to pathogens and the use of protein microarrays for detecting bioweapons pathogens. New sections on metagenomics, assembling genomes to produce manufactured viruses, and new information on the human papillomavirus vaccine, Gardasil.
- **Chapter 6: Plant Biotechnology** provides updates on how genetically engineered plants have been used to replace other crops for better pest resistance, higher yields, and new applications in fiber, bioplastics, biofuels, and bioremediation. New information on plant polyploids, and using plant material to make bioethanol production economical.
- **Chapter 7: Animal Biotechnology** provides updates on using mice with partial human immune systems for testing drug responses, the use of transgenic animals to produce vaccines, and using transgenic animal bioreactors for the production of complex therapeutic proteins.
- **Chapter 8: DNA Fingerprinting and Forensic Analysis** incorporates updates on uses of DNA sequence forensic information, identification of crime and catastrophe victims, establishing or excluding paternity relationships, authenticating food products, and other interesting aspects of forensic analysis.
- **Chapter 9: Bioremediation** includes a new section on the genomics of bioremediation and updated information on microbe-powered fuel cells, phytoremediation of explosives, and a new case study example.
- **Chapter 10: Aquatic Biotechnology** includes new information on using PCR to detect oyster pathogens, and new information on emerging medical products from aquatic organisms.
- **Chapter 11: Medical Biotechnology** provides updated information on gene therapy approaches including antisense methods and RNAi, updates and new information on regenerative medicine and tissue engineering, stem cell research and legislation and recent developments, and microarrays and pharmacogenomics.
- **Chapter 12: Biotechnology Regulations** incorporates new information on patenting gene sequences and world views on cloning and human stem cell use, compared to the United States.
- **Chapter 13: Ethics and Biotechnology** was rewritten to provide updated information on genetically modified foods, the genetic information nondiscrimination act, and stem cell regulations. It also includes a new section on patient rights and biological materials and three new *You Decide* entries.

Supplemental Learning Aids

Introduction to Biotechnology Companion Website (www.pearsonhighered.com/biotechnology)

The Companion Website is designed to help students study for their exams and deepen their understanding

of the text's content. Each chapter contains learning objectives, content reviews, flashcards, glossary terms, jpegs of figures, and an extensive collection of *Keeping Current Web Links* which explore related topics in other areas.

Instructor Resource Center (IRC)

The Instructor Resource Center www.pearsonhighered.com/educator is designed to support instructors teaching biotechnology. The IRC is an online resource that supports and augments material in the textbook. New instructor supplements available for download include:

- **Computerized Test Bank:** 10-20 multiple choice test questions per chapter
- **Jpeg Art Files:** electronic files of all text tables, line drawings, and photos
- **PowerPoint Lecture Outlines:** a set of PowerPoint presentations consisting of lecture outlines for each chapter augmented by key text illustrations

Instructors using *Introduction to Biotechnology* can contact their Benjamin Cummings sales representative to access the Instructor Resource Center free of charge.

Benjamin Cummings Special Topics in Biology Series

The *Benjamin Cummings Special Topics in Biology Series* is a series of booklets designed for undergraduate

students. These small booklets present the basic scientific facts and the social and ethical issues surrounding current hot topics. Booklets in the series include:

- *Alzheimer's Disease*
(ISBN 0-1318-3834-2)
- *Biology of Cancer*
(ISBN 0-8053-4867-0)
- *Biological Terrorism*
(ISBN 0-8053-4868-9)
- *Emerging Infectious Diseases*
(ISBN 0-8053-3955-8)
- *Genetic Testimony*
(ISBN 0-1314-2338-X)
- *Gene Therapy*
(ISBN 0-8053-3819-5)
- *HIV and AIDS*
(ISBN 0-8053-3956-6)
- *Mad Cows and Cannibals*
(ISBN 0-1314-2339-8)
- *Stem Cells and Cloning, 2e*
(ISBN 0-3215-9002-3)
NEW EDITION!
- *Understanding the Human Genome Project, 2e*
(ISBN 0-8053-4877-8)

Contact your local Benjamin Cummings sales representative about bundling booklets in this series with *Introduction to Biotechnology* or visit www.pearsonhighered.com for more information.

Acknowledgments

A textbook is the collaborative result of hard work from many dedicated individuals including students, colleagues, editors and editorial staff, graphics experts, and many others. First, we thank our family and friends for their support and encouragement while we spent countless hours of our lives on this project. Without your understanding and patience, this book would not be possible.

We gratefully acknowledge the help of many talented people at Benjamin Cummings, particularly the editorial staff. Editorial duties changed several times during the preparation of this edition, but each editor provided creative talents and dedication to the book. We thank Mercedes Grandin for her guidance and help with reviews during the transition between editions. Acquisitions Editor Becky Ruden has been the guiding force for the second edition and we are indebted to her for believing in the book's mission and for her vision to support and improve the text. Becky's leadership has been exactly what this project has needed, and she has been a great asset. We thank Project Editor Leata Holloway for keeping us on schedule and for her attention to detail, patience, enthusiasm, editorial suggestions, and great energy for the project.

We thank Production Supervisor Lori Newman for guiding us through the production process. Thanks go to Executive Marketing Manager Lauren Harp for her talents and creative contributions in developing promotional materials for this book. Maureen Spuhler, Photo Researcher, did a wonderful job of identifying and securing key art and suggesting alternatives. We thank Maria McColligan, Project Manager at Nesbitt Graphics, Inc., for her expert work on the first and second editions of the textbook. We'd also like to thank cover designer Rich Leeds of Big Wig Design who leant a fresh new look for the 2nd edition and Anne Lesser for expert copyediting.

Undergraduate students at Monmouth University read many drafts of the manuscript for the first and second edition and critiqued art scraps for clarity and content. We thank former students in BY 201 – Intro-

duction to Biotechnology for their honest reviews, error finding, and suggestions from a student's perspective. In particular we thank Monica Gionet who was especially skilled at noting points of clarification prior to completing the second edition. We also thank Monmouth University graduate Robert Sexton for contributing to the Career Profile section of Chapter 3. The 2002 Introductory Biotechnology class students at Ventura College provided many useful suggestions while they tolerated the use of the "sketchy figures" in PowerPoint programs, which were the result of our first draft. Our students inspire us to strive for better ways to help us teach and to help them understand the wonders of biotechnology. We applaud you for your help in creating what we hope future students will deem to be a student-friendly textbook.

We also thank Dr. Daniel Rudolph for contributing to the Career Profile in Chapter 5 (Microbial Biotechnology) and Gef Flimlin for contributing to the Career Profile in Chapter 10 (Aquatic Biotechnology).

Finally, *Introduction to Biotechnology* has greatly benefited from valued input of many colleagues and instructors who helped us with scientific accuracy, clarity, pedagogical aspects of the book, and suggestions for improving drafts of each chapter. The many instructors who have developed biotechnology courses and programs and enthusiastically teach majors and nonmajors about biotechnology provided reviews of the text and art that have been invaluable for helping shape this textbook. Your constructive criticism helped us to revise drafts of each chapter, and your words of praise helped inspire us to move ahead. All errors or omissions in the text are our responsibility. We thank you all and look forward to your continued feedback. Reviewers of *Introduction to Biotechnology*, include:

For the second edition:

Steve Benson *California State University East Bay*
Ming-Mei Chang *SUNY Genesco*
Jim Cheaney *Iowa State University*
Peter Eden *Marywood University*

Timothy S. Finco *Agnes Scott College*
 Mary A. Farwell *East Carolina University*
 James T. Hsu *Lehigh University*
 Lisa Johansen *University of Colorado, Denver*
 Michael Lawton *Rutgers University*
 Caroline Mackintosh *University of Saint Mary*
 Toby Mapes *A B Tech Community College*
 Patricia Phelps *Austin Community College*
 Ronald Raab *James Madison University*
 Melody Ricci *Victor Valley College*
 Bill Sciarrapa *Rutgers University*
 Salvatore A. Sparace *Clemson University*
 Janice Toyoshima *Evergreen Valley College*
 Dennis Walsh *Massachusetts Bay Community College*
 Lianna Wong *Santa Clara University*

For the first edition:

D. Derek Aday *Ohio State University*
 Marcie Baer *Shippensburg University*
 Joan Barber *Delaware Tech & Community College*
 Theresa Beaty *LeMoyne College*
 Peta Bonham-Smith *University of Saskatchewan*
 Krista Broten *University of Saskatchewan*
 Heather Cavenagh *Charles Sturt University*
 Wesley Chun *University of Idaho*
 Mark Flood *Fairmont State College*
 Kathryn Paxton George *University of Idaho*
 Joseph Gindhart *University of Massachusetts, Boston*
 Jean Hardwick *Ithaca College*
 George Hegeman *Indiana University, Bloomington*
 Anne Helmsley *Antelope Valley College*
 David Hildebrand *University of Kentucky*
 Paul Horgen *University of Toronto at Mississauga*
 James Humphreys *Seneca College of Applied Arts & Technology*
 Tom Ingebritsen *Iowa State University*
 Ken Kubo *American River College*
 Theodore Lee *SUNY Fredonia*
 Edith Leonhardt *San Francisco City College*

Lisa Lorenzen Dahl *Iowa State University*
 Keith McKenney *George Mason University*
 Timothy Metz *Campbell University*
 Robert Pinette *University of Maine*
 Lisa Rapp *Springfield Technical Community College*
 Stephen Rood *Fairmont State College*
 Alice Sessions *Austin Community College*
 Carl Sillman *Pennsylvania State University*
 Teresa Singleton *Delaware State University*
 Sharon Thoma *Edgewood College*
 Danielle Tilley *Seattle Community College*
 Jagan Valluri *Marshall University*
 Brooke Yool *Ohlone College*
 Mike Zeller *Iowa State University*

Whether you are a student or instructor, we invite your comments and suggestions for improving the next edition of *Introduction to Biotechnology*. Please write to us at the following addresses below or contact us via e-mail at bc.feedback@pearson.com.

Bill Thieman
 Ventura College
 Department of Biology
 4667 Telegraph
 Ventura, CA 93003
BThieman@vcccd.edu

Michael Palladino
 Monmouth University
 School of Science, Technology and Engineering
 Department of Biology
 400 Cedar Avenue
 West Long Branch, NJ 07764
www.monmouth.edu/mpalladi

As students ourselves, we too continue to learn about biotechnology everyday. We wish you great success in your explorations of biotechnology!

W. J. T.
 M. A. P.

Contents

About the Authors vii

Preface viii

1 The Biotechnology Century and Its Workforce 1

1.1 What Is Biotechnology and What Does It Mean to You? 2

A Brief History of Biotechnology 2

Biotechnology: A Science of Many Disciplines 5

Products of Modern Biotechnology 6

Ethics and Biotechnology 8

1.2 Types of Biotechnology 8

Microbial Biotechnology 8

Agricultural Biotechnology 8

Animal Biotechnology 10

Forensic Biotechnology 10

Bioremediation 11

Aquatic Biotechnology 12

Medical Biotechnology 12

Regulatory Biotechnology 13

The Biotechnology “Big Picture” 13

1.3 Biological Challenges of the 21st Century 14

What Will the New Biotechnology Century Look Like? 14

A Scenario in the Future: How Might We Benefit from the Human Genome Project? 14

1.4 The Biotechnology Workforce 18

The Business of Biotechnology 19

Organization of a Biotechnology Company 19

Jobs in Biotechnology 20

Salaries in Biotechnology 23

Hiring Trends in the Biotechnology Industry 24

Questions & Activities 25

References and Further Reading 25

2 An Introduction to Genes and Genomes 26

2.1 A Review of Cell Structure 27

Prokaryotic Cells 27

Eukaryotic Cells 28

2.2 The Molecule of Life 30

Evidence That DNA Is the Inherited Genetic Material 30

DNA Structure 32

What Is a Gene? 33

2.3 Chromosome Structure, DNA Replication, and Genomes 33

Chromosome Structure 34

DNA Replication 37

What Is a Genome? 38

2.4 RNA and Protein Synthesis 39

Copying the Code: Transcription 40

Translating the Code: Protein Synthesis 43

Basics of Gene Expression Control 46

2.5 Mutations: Causes and Consequences 51

Types of Mutations 51

Mutations Can Be Inherited or Acquired 53

Mutations Are the Basis of Variation in Genomes and a Cause of Human Genetic Diseases 54

Questions & Activities 55

References and Further Reading 56

3 Recombinant DNA Technology and Genomics 57

3.1 Introduction to Recombinant DNA Technology and DNA Cloning 58

Restriction Enzymes and Plasmid DNA Vectors 58

Transformation of Bacterial Cells and Antibiotic
Selection of Recombinant Bacteria 61
Introduction to Human Gene Cloning 63

3.2 What Makes a Good Vector? 65

Practical Features of DNA Cloning Vectors 65
Types of Vectors 66

3.3 How Do You Identify and Clone a Gene of Interest? 68

Creating DNA Libraries: Building a Collection
of Cloned Genes 68
Polymerase Chain Reaction 71

3.4 What Can You Do with a Cloned Gene? Applications of Recombinant DNA Technology 75

Gel Electrophoresis and Mapping Gene
Structure with Restriction Enzymes 75
DNA Sequencing 78
Chromosomal Location and Gene Copy
Number 80
Studying Gene Expression 81
Northern Blot Analysis 82

3.5 Genomics and Bioinformatics: Hot New Areas of Biotechnology 87

Bioinformatics: Merging Molecular Biology
with Computing Technology 87
Examples of Bioinformatics in Action 87
A Genome Cloning Effort of Epic Proportion:
The Human Genome Project 89
What Have We Learned from the Human
Genome? 90
The Human Genome Project Started
an “Omics” Revolution 92
Comparative Genomics 92
Stone Age Genomics 93
Questions & Activities 95
References and Further Reading 95

4 Proteins as Products 97

4.1 Introduction to Proteins as Biotech Products 98

4.2 Proteins as Biotechnology Products 98

Making a Biotech Drug 99
Medical Applications 100
Food Processing 100
Textiles and Leather Goods 101
Detergents 101
Paper Manufacturing
and Recycling 101

Adhesives: Natural Glues 101
Bioremediation: Treating Pollution with
Proteins 102

4.3 Protein Structures 102

Structural Arrangement 102
Protein Folding 103
Glycosylation 104
Protein Engineering 104

4.4 Protein Production 106

Protein Expression: The First Phase in Protein
Processing 107

4.5 Protein Purification Methods 109

Preparing the Extract for Purification 109
Stabilizing the Proteins in Solution 109
Separating the Components in the Extract 110

4.6 Verification 114

4.7 Preserving Proteins 115

4.8 Scale-up of Protein Purification 116

4.9 Postpurification Analysis Methods 116

Protein Sequencing 116
X-ray Crystallography 116

4.10 Proteomics 117

Questions & Activities 118
References and Further Reading 118

5 Microbial Biotechnology 119

5.1 The Structure of Microbes 120

Yeast Are Important Microbes Too 121

5.2 Microorganisms as Tools 122

Microbial Enzymes 123
Bacterial Transformation 123
Electroporation 124
Cloning and Expression Techniques 125

5.3 Using Microbes for a Variety of Everyday Applications 127

Food Products 127
Therapeutic Proteins 131
Using Microbes Against Other Microbes 131
Field Applications of Recombinant
Microorganisms 134

5.4 Vaccines 135

A Primer on Antibodies 136
How Are Vaccines Made? 137
Bacterial and Viral Targets for
Vaccines 139

5.5 Microbial Genomes 141

- Why Sequence Microbial Genomes? 141
- Microbial Genome Sequencing Strategies 142
- Selected Genomes Sequenced to Date 142
- Sorcerer II: Traversing the Globe to Sequence Microbial Genomes 143
- Viral Genomics 144
- Assembling Genomes to Produce Human-Made Viruses 145

5.6 Microbial Diagnostics 145

- Bacterial Detection Strategies 145
- Tracking Disease-Causing Microorganisms 147
- Microarrays for Tracking Contagious Diseases 147

5.7 Combating Bioterrorism 148

- Microbes as Bioweapons 149
- Targets of Bioterrorism 150
- Using Biotechnology Against Bioweapons 151
- Questions & Activities** 153
- References and Further Reading** 154

6 Plant Biotechnology 155

6.1 Agriculture: The Next Revolution 156

6.2 Methods Used in Plant Transgenesis 157

- Conventional Selective Breeding and Hybridization 157
- Cloning: Growing Plants from Single Cells 157
- Protoplast Fusion 157
- Leaf Fragment Technique 158
- Gene Guns 158
- Chloroplast Engineering 159
- Antisense Technology 159

6.3 Practical Applications in the Field 161

- Vaccines for Plants 161
- Genetic Pesticides: A Safer Alternative? 162
- Safe Storage 163
- Herbicide Resistance 163
- Stronger Fibers 163
- Enhanced Nutrition 164
- The Future: From Pharmaceuticals to Fuel 164
- Metabolic Engineering 166

6.4 Health and Environmental Concerns 167

- Concerns About Human Health 168
- Concerns About the Environment 168
- Regulations 169
- Questions & Activities** 170
- References and Further Reading** 170

7 Animal Biotechnology 171

7.1 Introduction to Animal Biotechnology 172

7.2 Animals in Research 172

- Animal Models 172
- Alternatives to Animal Models 174
- Regulation of Animal Research 175
- Veterinary Medicine as Clinical Trials 176
- Bioengineering Mosquitoes to Prevent Malaria 177

7.3 Clones 177

- Creating Dolly: A Breakthrough in Cloning 177
- The Limits to Cloning 178
- The Future of Cloning 179

7.4 Transgenic Animals 180

- Transgenic Techniques 180
- Improving Agricultural Products with Transgenics 181
- Transgenic Animals as Bioreactors 183
- Knockouts: A Special Case of Transgenics 184

7.5 Producing Human Antibodies in Animals 186

- Monoclonal Antibodies 186
- Eggs as Antibody Factories 188
- Questions & Activities** 188
- References and Further Reading** 189

8 DNA Fingerprinting and Forensic Analysis 190

8.1 Introduction to DNA Fingerprinting and Forensics 191

8.2 What Is a DNA Fingerprint? 191

- How Is DNA Typing Performed? 191

8.3 Preparing a DNA Fingerprint 192

- Specimen Collection 192
- Extracting DNA for Analysis 193
- Restriction Fragment Length Polymorphism (RFLP) Analysis 193
- The Southern Blot Technique 193
- PCR and DNA Amplification 196
- Dot Blot (or Slot Blot) Analysis 196
- STR Analysis 196

8.4 Putting DNA to Use 196

- The Narborough Village Murders 197
- The Forest Hills Rapist 197

Terrorism and Natural Disasters Force
Development of New Technologies 199

- 8.5 DNA and the Rules of Evidence** 200
DNA Fingerprinting and the Simpson and
Goldman Murders 201
Human Error and Sources of Contamination 201
DNA and Juries 202
- 8.6 Familial Relationships and
DNA Profiles** 202
Mitochondrial DNA Analysis 202
Y-Chromosome Analysis 203
- 8.7 Nonhuman DNA Analysis** 204
DNA Tagging to Fight Fraud 206
Questions & Activities 206
References and Further Reading 207

9 Bioremediation 208

- 9.1 What Is Bioremediation?** 209
Why Is Bioremediation Important? 209
- 9.2 Bioremediation Basics** 210
What Needs to Be Cleaned Up? 210
Chemicals in the Environment 211
Fundamentals of Cleanup Reactions 211
The Players: Metabolizing Microbes 213
Bioremediation Genomics Programs 215
- 9.3 Cleanup Sites and Strategies** 217
Soil Cleanup 217
Bioremediation of Water 218
Turning Wastes into Energy 220
- 9.4 Applying Genetically Engineered Strains
to Clean Up the Environment** 222
Petroleum-Eating Bacteria 222
Engineering *E. coli* to Clean Up Heavy Metals 223
Biosensors 224
Genetically Modified Plants and
Phytoremediation 224
- 9.5 Environmental Disasters: Case Studies in
Bioremediation** 225
Jet Fuel and Hanahan, South Carolina 225
The Exxon Valdez Oil Spill 225
Oil Fields of Kuwait 226
- 9.6 Future Strategies and Challenges
for Bioremediation** 227
Recovering Valuable Metals 228
Bioremediation of Radioactive Wastes 229
Questions & Activities 230
References and Further Reading 230

10 Aquatic Biotechnology 231

- 10.1 Introduction to Aquatic
Biotechnology** 232
- 10.2 Aquaculture: Increasing
the World's Food Supply
Through Biotechnology** 232
The Economics of Aquaculture 232
Fish Farming Practices 235
Improving Strains for Aquaculture 238
Enhancing Seafood Quality and Safety 239
Barriers and Limitations to Aquaculture 239
The Future of Aquaculture 242
- 10.3 Molecular Genetics of Aquatic
Organisms** 242
Discovery and Cloning of Novel Genes 242
Genetic Manipulations of Finfish and
Shellfish 247
- 10.4 Medical Applications of Aquatic
Biotechnology** 251
Drugs and Medicines from the Sea 251
Monitoring Health and Human Disease 254
- 10.5 Nonmedical Products** 254
A Potpourri of Products 254
Biomass and Bioprocessing 255
- 10.6 Environmental Applications of Aquatic
Biotechnology** 256
Antifouling Agents 256
Biosensors 257
Environmental Remediation 257
Questions & Activities 259
References and Further Reading 259

11 Medical Biotechnology 260

- 11.1 The Power of Molecular Biology:
Detecting and Diagnosing Human Disease
Conditions** 261
Models of Human Disease 261
Biomarkers for Disease Detection 263
Detecting Genetic Diseases 263
- 11.2 Medical Products and Applications of
Biotechnology** 268
The Search for New Medicines and Drugs 269
Artificial Blood 273
Vaccines and Therapeutic Antibodies 273
- 11.3 Gene Therapy** 275
How Is It Done? 275

Curing Genetic Diseases: Targets for Gene Therapy 279
Challenges Facing Gene Therapy 281

11.4 The Potential of Regenerative Medicine 282

Cell and Tissue Transplantation 282
Tissue Engineering 285
Stem Cell Technologies 287
Cloning 293
Embryonic Stem Cell and Therapeutic Cloning
Regulations in the United States 297

11.5 The Human Genome Project Has Revealed Disease Genes on All Human Chromosomes 298

Piecing Together the Human Genome
Puzzle 298
Questions & Activities 303
References and Further Reading 303

12 Biotechnology Regulations 305

12.1 The Regulatory Framework 306

12.2 U.S. Department of Agriculture 308

Animal and Plant Health Inspection
Service 308
Permitting Process 308
The APHIS Investigative Process 308
The Notification Process 309

12.3 The Environmental Protection Agency 309

Experimental Use Permits 309
The First Experimental Use Permit 309
Deregulation and Commercialization 310

12.4 Food and Drug Administration 311

Food and Food Additives 311
The Drug Approval Process 311
Good Laboratory (GLP), Clinical (GCP), and
Manufacturing (GMP) Practices 312
Phase Testing of Drugs 312
Faster Drug Approval versus Public
Safety 313

12.5 Legislation and Regulation: The Ongoing Role of Government 314

Labeling Biotechnology Products 316
The Fluvirin Failure 316

12.6 Introduction to Patents 317

The Value of Patents in the Biotechnology
Industry 318
Patenting DNA Sequences 319

12.7 Biotechnology Products in the Global Marketplace 321

Questions & Activities 322
References and Further Reading 323

13 Ethics and Biotechnology 324

13.1 What Is Ethics? 325

Approaches to Ethical Decision Making 325
Ethical Exercise Warm-Up 326

13.2 Biotechnology and Nature 327

Cells and Products 328
GM Crops: Are You What You Eat? 328
Animal Husbandry or Animal Tinkering? 331
The Human Question 332
What Does It Mean to Be Human? 333
Spare Embryos for Research Versus Creating
Embryos for Research 335
Cloning 336
Patient Rights and Biological Materials 337
Regulations in Flux 338
Your Genes, Your Self 338
More or Less Human? 339

13.3 Economics, the Role of Science, and Communication 340

Questions & Activities 342
References and Further Reading 343

Appendix 1 Answers to Questions &
Activities A-1

Appendix 2 The 20 Amino Acids of
Proteins A-9

Credits C-1

Glossary G-1

Index I-1