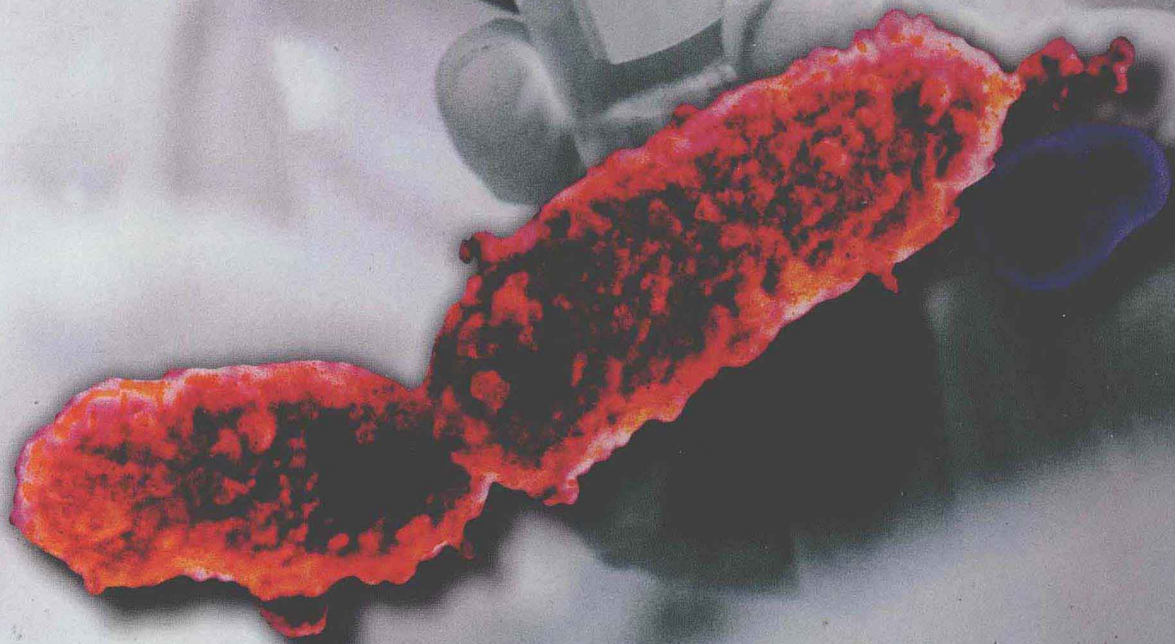


Nester · Roberts · Pearsall · Anderson · Nester

MICROBIOLOGY

A Human Perspective



Second Edition

Second Edition

MICROBIOLOGY

A Human Perspective

Eugene W. Nester, C. Evans Roberts

University of Washington

Nancy N. Pearsall

Denise G. Anderson

University of Washington

Martha T. Nester



Boston, Massachusetts Burr Ridge, Illinois Dubuque, Iowa
Madison, Wisconsin New York, New York San Francisco, California St. Louis, Missouri

WCB/McGraw-Hill

A Division of The McGraw-Hill Companies

MICROBIOLOGY: A HUMAN PERSPECTIVE

Copyright 1998 by The McGraw-Hill Companies, Inc. All rights reserved. Previous edition 1995 by Wm. C. Brown Communications, Inc. 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.



This book is printed on recycled, acid-free paper containing 10% postconsumer waste.

4 5 6 7 8 9 0 VNHVNH 0

ISBN 0-697-28602-9

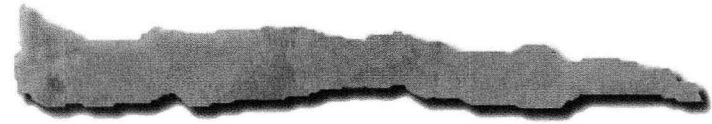
Vice President, Editorial director: Keven T. Kane
Publisher: James M. Smith
Sponsoring editor: Ronald E. Worthington, Ph.D.
Developmental editor: Terrance Stanton
Marketing manager: Thomas C. Lyon
Project manager: Marilyn M. Sulzer
Production supervisor: Laura Fuller
Cover designer: Kristyn Kalnes
Cover photo: Lab Technician © Tony Stone Images
Inset: © Pasteur/Phototake
Interior designer: Jeff Storm
Photo research coordinator: Lori Hancock
Art editor: Jodi K. Banowetz
Compositor: PC&F, Inc.
Typeface: 10/12 Palatino
Printer: Von Hoffman Press, Inc.

Library of Congress Cataloging-in-Publication Data

Microbiology : a human perspective --2nd ed. / Eugene W. Nester . . .
[et al.]
p. cm.
Rev. ed. of: Microbiology / Eugene W. Nester. c1995.
Includes bibliographical references and index.
ISBN 0-697-28602-9
1. Microbiology. I. Nester, Eugene W.
QR41.2.N47 1998
579--DC21

97-15264
CIP

www.mhhe.com



We dedicate this book to our students; we hope it helps to enrich their lives and to make them better informed citizens,

to our families whose patience and endurance made completion of this project a reality,

to Anne Nongthanat Panarak Roberts in recognition of her invaluable help, patience, and understanding,

to our colleagues for continuing encouragement and advice.

PREFACE

As everyone who tries to teach or learn microbiology knows, the amount of new information to be sifted and sorted has grown enormously in recent years. The number of new microbiological terms is enough to constitute a new language. Donald P. Hayes writes about the "Growing Inaccessibility of Science" (*Nature* 356:739, April 30, 1992) and the flight of readers from journals that fail to make their articles intelligible to their readership.

A colleague of ours who had recently published a textbook was told by one of his students, "Great book. Too bad I have no time to read it." There is good reason to believe that students generally have less time to cover more material than they did a few years ago. We have tried to avoid the chatty, superficial style and lavish illustrations used by some of the more recent texts, in favor of clarity and conciseness.

Organization and Approach

A textbook is not a novel. Few students will read a text from cover to cover, and instructors generally like to pick and choose among chapters. We have therefore used judicious redundancy to help the chapters stand alone. The text is organized into 34 chapters grouped into four parts. The first nine chapters (Part One) focus on presenting the basic principles of microbiology, with an emphasis on indicating the relevance of these principles to human health. Because basic chemistry concepts are important to the study of microbiology, we have included a chemistry chapter in Part One for those students with little or no background in this area. Part One also contains a chapter on microbiology and biotechnology in which we present up-to-date, relevant information on genetic engineering and technological advances, such as the polymerase chain reaction, which has an important impact on human society today.

Part Two (chapters 10–14) provides a survey of the major types of microorganisms and viruses, and a discussion on how they are classified and identified.

In Parts Three and Four, previous users of the book will notice some reorganization of chapter content and sequence. We have added an additional chapter on immunology. This rapidly expanding topic is now covered in chapters 15 through 18. Host-parasite interactions are now covered in chapter 19, and the coverage of antimicrobial

and antiviral medicines has been moved forward, to chapter 21. Part Three (chapters 15–31) covers the many important aspects of the interactions between microorganisms and humans, including immunology, epidemiology, a survey of infectious diseases, and the action of antimicrobial and antiviral medicines. In the chapters on infectious diseases, we employ an "organ-system" approach to organizing the material presented. The significant change in this section is a chapter devoted to blood and lymphatic infections (chapter 30), and a full chapter (31) devoted to AIDS and complications of immunodeficiency disorders.

Also new in the disease-focused chapters are case studies that relate factual information to actual clinical situations. Finally, Part Four (chapters 32–34) discusses environmental microbiology and the microbiology of food and beverages.

Experience has shown that few instructors attempt to cover multicellular parasites, but those who do feel strongly that they should be included. We, therefore, have placed a section on multicellular parasitology in an appendix (appendix VII). Reference sections on diseases and microorganisms are found in appendices IV and V. There are also appendices covering microbial mathematics (appendix I), pH (appendix II), glucose degradation pathways (appendix III), and immunizing agents (appendix VI).

Learning Aids for the Student

In order for students to succeed in their study of microbiology, they must be able to understand the material presented, utilize the text as a tool for learning, and enjoy reading the text. Therefore, we have included many aids to make the study of microbiology efficient and enjoyable. Each chapter contains the following:

1. **Chapter Opening Key Concepts** The chapter opening key concepts were written to help the student preview the major concepts to be covered and understood in the chapter.
2. **Chapter Opening "Glimpse of History"** The chapter opening "Glimpse of History" sections are designed to help the student "see" the relevance of historical events in microbiology to what they study today and

understand the importance of the scientific method. The “Glimpse of History” from page 3 is reproduced here.

3. **Chapter Opening Introduction** A brief preview of the chapter’s contents, which relates it to other chapters within the text. This introduction is designed to help the student put the chapter into perspective at the start of their study of a specific topic.
4. **Declarative Statement Heads** Clear statements to help introduce students to each important topic.
5. **Boldfaced Key Terms** Important terms are emphasized and clearly defined when they are first presented.
6. **Cross-reference Notes** These notes refer the student to major topics that are difficult and which may need to be reviewed in order to understand the current material. An example of the usage of a cross-reference note from page 7 has been reproduced here.

In addition to well-accepted diseases, maladies that were attributed to other causes have now been shown to be caused by microorganisms. One well-known example is peptic ulcers. This common affliction has recently been shown to be caused by a bacterium and to be treatable by antibacterial agents. It seems likely that other maladies whose causes are not understood will be shown to be caused by microorganisms or other agents of infectious disease.

• **Ulcers, p. 564**

7. **End-of-page Footnotes** These footnotes provide students with on-page explanations and definitions for particularly difficult concepts and terms.
8. **Review Questions After Major Chapter Sections** These review questions help students test their knowledge and understanding of the section’s factual material and major concepts before continuing on to the next section of the chapter.
9. **Chapter Review Questions** At the end of each chapter, a set of 10 questions tests students’ knowledge of the entire chapter.
10. **Summary Tables** The summary tables are designed to help students organize their thoughts on important facts or characteristics presented for a specific topic.
11. **New Case Presentation** In the chapters (22–31) that focus on human diseases, we now include *case presentations*: actual clinical reports that relate the chapter’s information to the experiences of patients and physicians, nurses, and medical personnel.
12. **“Perspective” Box Readings** Most chapters contain at least one “Perspective” box reading. These box readings cover a wide variety of interesting topics. Topics include recent developments in biotechnology, items of medical significance, applications of microbial activities, and descriptions of unusual microorganisms. Perspective 2.2 from page 27 is shown here.

A Glimpse of History

Microbiology was born in 1674 when Antony van Leeuwenhoek (1632–1723), an inquisitive Dutch drapery merchant, peered at a drop of lake water through a carefully ground glass lens. What he observed through this simple magnifying glass was undoubtedly one of the most startling and amazing sights that humans have ever beheld—the first glimpse of the world of microbes. As recorded in a letter to the Royal Society of London, van Leeuwenhoek saw

“... Very many little animalcules, whereof some were roundish, while others a bit bigger consisted of an oval. On these last, I saw two little legs near the head, and two little fins at the hind most end of the body. Others were somewhat longer than an oval, and these were very slow a-moving, and few in number. These animalcules had diverse colours, some being whitish and transparent; others with green and very glittering little scales, others again were green in the middle, and before and behind white; others yet were ashed grey. And the motion of most of these animalcules in the water was so swift, and so various, upwards, downwards, and round about, that ’twas wonderful to see. . . .”

From descriptions, it is clear that van Leeuwenhoek saw representatives of all the groups of microorganisms.

Perspective 2.2

Water—The Universal Requirement for Life

The properties of water depend on the properties of its constituent atoms, hydrogen (H) and oxygen (O), as well as on the bonds that join the atoms together. Since the O, covalently bonded to H, attracts electrons more strongly than the H, water is a highly polar molecule, with the O having a negative charge and the H a positive charge (see figure 2.3). This polar nature of water is important in biology. First, it enables each water molecule to form hydrogen bonds with four other water molecules, leading to a strong attraction between water molecules (figure 1).

The strong attraction requires that a large amount of heat be applied to break the bonds between water molecules. This explains why water is a liquid at room temperature and that a great deal of heat is required to convert it into a gas. This fact is significant because water vapor (gas) is not important in biological systems, whereas the liquid form is very important.

The polar nature of water also accounts for its ability to dissolve a large number of compounds, another feature important for life as we know it. Water-soluble compounds contain atoms with positive or negative charges; in water they ionize, or split, into charged atoms. A positive charge means that the ion has one proton more than it has electrons. A negative charge means that the ion has one more electron than it has protons. For example, NaCl dissolves in water to form Na⁺ ions, termed **cations**, because they move towards the cathode in an electrical field, and Cl[−] ions, termed **anions**, because they move toward the positively charged anode. In solution, ions such as Na⁺ and Cl[−] tend to be surrounded by water molecules in such a way that the O[−] of HOH forms weak bonds with Na⁺, and the H⁺ forms weak bonds with Cl[−] (figure 2).

This prevents the Na⁺ and Cl[−] from coming together, and it accounts for the solubility of NaCl in water. Nonpolar molecules such as fats and hydrocarbons are insoluble in water; but thus are soluble in uncharged (nonpolar) solvents such as benzene. Indeed, when a nonpolar liquid such as oil is mixed with a polar liquid such as water, the two do not mix. This phenomenon explains why oil and vinegar, which is dilute acetic acid, separate in salad dressing.

Another important feature of aqueous solutions is their level of acidity, or pH. This aspect is discussed in appendix II.

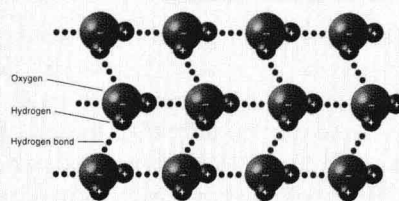


Figure 1
Water molecules held in a latticework, illustrating the hydrogen bonding among molecules.

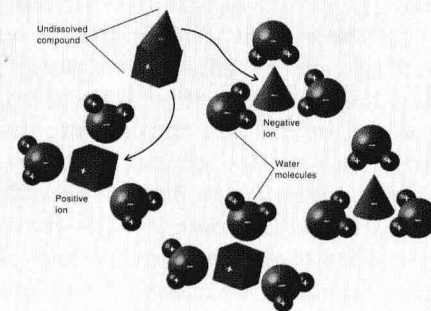


Figure 2
Water dissolving a compound that is made up of positive and negative charges. The charged regions of the water molecules surround the ions and keep them from associating with each other.

13. **Chapter Summary in Outline Form** This outline of important chapter concepts is designed to serve as a guide for chapter study.

14. **End-of-chapter Critical Thinking Questions** The “Critical Thinking Questions” are meant to aid the student in reviewing, integrating, and applying the concepts and principles learned from the chapter.
15. **End-of-chapter Further Readings** References are provided for further investigation or study of important topics.

In addition to these chapter aids, the text also features the following:

1. **Chapter Specific Study Cards** Chapter specific study cards for chapters 22–31 are bound within Part Three of the text. These cards can easily be torn out of the text to aid the student in studying key diseases, their causative microorganisms and significant features; even when they don’t have their book in hand.
2. **Multimedia-supported Microbiological Concepts and Processes Illustrations** Throughout the text, the reader will find *illustrations* of microbiological concepts and processes that can be supplemented with full color video and/or animations from an interactive Multimedia program, *Microbes in Motion*, available from WCB/McGraw-Hill. The reader will be able to easily recognize these figures, as the figure legends are preceded by a CD icon. Figure 3.27, page 64, is one example of such an illustration.
3. **Preview Links to *Microbes in Motion* CD-Rom.** Each chapter-opening page contains a “Preview Link” that refers to specific parts of *Microbes in Motion* that will help a student comprehend the material or explore concepts further.



PREVIEW LINK

Microbes in Motion

The following books and chapters in the *Microbes in Motion* CD-ROM may serve as a useful preview or supplement to your reading:

Bacterial Structure and Function: Internal Structures; Cell Walls; Bacterial Groups. *Viral Structure and Function*: Viral Structure.

4. **Glossary** Definitions of boldface terms are assembled in the glossary at the end of the text. A pronunciation guide for the names of microorganisms is also included.
5. **Appendices** The appendices aid the student with extra review information on microbial mathematics, pH, metabolic pathways, bacteria of medical importance, parasitic diseases, and immunizing agents.
6. **Index** An easy to use, comprehensive index is provided.
7. **Endsheets with Reference Material** The endsheets of the text contain useful reference information and a summary table of “Diseases and Their Causative Microorganisms.”

Supplementary Materials

For the Instructor

1. An *Instructor’s Manual with Test Item File*, written by Clementine A. deAngelis, Tarrant County Junior College, features a chapter introduction, chapter objectives, important terms, and answers for in-text review questions and end-of-chapter critical thinking questions for each text chapter. Suggestions for appropriate audiovisual materials are also included. In addition, the manual offers an average of 50 objective test questions per chapter that can be used to generate exams. (ISBN 28604)
2. A *Computerized Testing and Classroom Management Service* is offered free upon request to adopters of this text. The service provides a database of objective questions for preparing exams, and a grade-recording program. The software requires no programming experience and is available in Windows and Macintosh formats: Windows 3.5 (ISBN 14021), and Mac 3.5 (ISBN 14023)
3. A set of 200 full-color acetate *transparencies* is available free to adopters and may be used to supplement classroom lectures. (ISBN 28607)
4. A set of 50 color *projection slides* derived from in-text photos is available. (ISBN 28606)

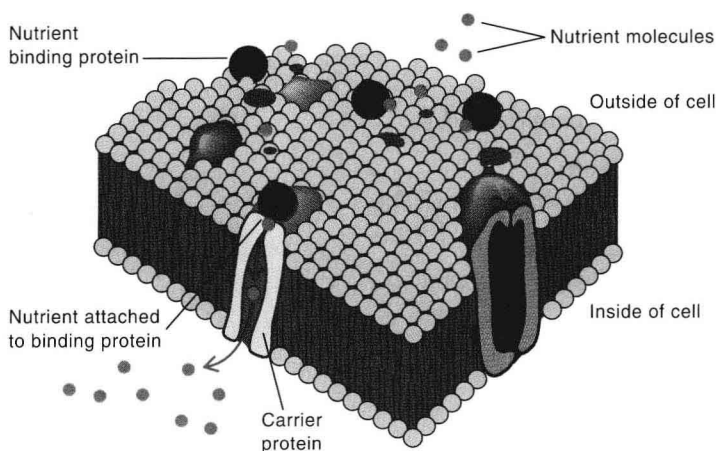


Figure 3.27

Active transport by means of specific binding proteins. These proteins are in the periplasm in gram-negative cells and are attached to the cytoplasmic membrane in gram-positive cells. The binding proteins interact with carrier proteins in the membrane. This process is rapid and results in the accumulation of the small molecules inside the cell.

5. The second edition of *Experiments in Microbiology: A Health Science Perspective* by John Kleyn, Marie Gilstrap, and Mary Bicknell, University of Washington, has been prepared to supplement this text. This manual contains references to this text, but can also be easily used to supplement other microbiology textbooks. Like this text, the laboratory manual provides a human health perspective in its presentation of laboratory techniques and microbiological principles. Each exercise in this manual is also available as a customized, one-color separate. Specific lab exercises can be combined with one's own materials. Contact the local Wm. C. Brown Publishers representative for more details on the custom publishing service. (ISBN 28598)

For the Student

1. A *Student Study Guide* by William O'Dell, University of Nebraska–Omaha, contains chapter introductions, key concepts, summaries, terms and definitions tests, reading material tests, and review questions to aid the student's comprehension of each chapter within the text. (ISBN 28605)
2. A set of 300, 3" × 5" *Microbiology Study Cards* prepared by Kent M. Van de Graaff, F. Brent Johnson, Brigham Young University, and Christopher H. Creek feature complete descriptions of terms, clearly labeled drawings, clinical information on diseases, and much more. (ISBN 10979)

Acknowledgments

We thank our colleagues in the Department of Microbiology at the University of Washington who have lent their support of this project over many years. Our special thanks goes to: Neal Groman for his contribution to the material on pathogenesis, James T. Staley for advice on classification of the prokaryotes, Mary Bicknell for reviewing the manuscript, and Tom Fritsche, Sam Eng, and the late Fritz Schoenknecht for their help with illustrating clinical material.

In addition, we thank the many others who helped at various times in the preparation of the manuscript. They include Sharon Bradley, Virginia Dillard, Ramona Finical, Lynn Gottlieb, Jane Halsey, Kirsten Nester, Catherine Pousson, Katie Rhodes, Jean Roberts, and Wendy Staley.

We wish to extend a special thank you to our many colleagues across the country for reviewing the manuscript and making many helpful suggestions.

Steve K. Alexander

University of Mary Hardin-Baylor

Peter Amborse

Columbia Greene Community College

D. Andy Anderson

East Utah State University

Rodney P. Anderson

Ohio Northern University

Len M. Archer

Florida Hospital College of Health Sciences

Gail Baker

LaGuardia Community College

Russell G. Barnekow, Jr.

Southwest Missouri State University

Robert Bauman, Jr.

Amarillo College

David Berryhill

North Dakota State University

Peter Biesemeyer

North Country Community College

Edward Botan

Nashua Scientific Consultants

Thomas Byrne

Roane State Community College

Alfred E. Brown

Auburn University

Wade Collier

Manatee Community College

John R. Crooks

Iowa Wesleyan College

Clementine A. deAngelis

Tarrant County Junior College

Joseph DePierro

Nassau Community College

Ellen Digan

Manchester Community College

Elizabeth Doller

Parker College of Chiropractic

Bruce Evans

Huntington College

Edward R. Fliss

Missouri Baptist College

Steven Forst

University of Wisconsin–Milwaukee

Pamela B. Fouche

Walters State Community College

Marc Franco
South Seattle Community College

Rebecca Halyard
Clayton State College

Anne Heise
Washtenaw Community College

Dr. Donald Hicks
Los Angeles City College

Sonja L. Hyduke
Polk Community College

William J. Lembeck
Louisiana State University at Eunice

Lisa Lemke
Sussex County Community College

William Marshall
New York Medical College

John Natalini
Quincy University

William D. O'Dell
University of Nebraska at Omaha

Leba Sarkis
Aims Community College

Thomas Secrest
Austin Community College

Brian Shmaefsky
Kingwood College

C. V. Sommer
University of Wisconsin–Milwaukee

Philip Stukus
Denison University

Donald L. Terpening
Ulster County Community College

Jun Tsuji
Siena Heights College

Ed Ward
Alabama A&M University

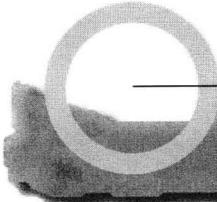
Vernon L. Wranosky
Colby Community College

Once again, Iris Nichols has completed, reviewed, and updated the line art widely acclaimed in our past editions, and created many new figures. We are indebted to her and to Will Agranoff, who assisted with the computer-generated line art pieces. We are also grateful for the skillful assistance of the Wm. C. Brown/McGraw-Hill staff, especially Liz Sievers, our editor; Terry Stanton, developmental editor; Lori Hancock, photo editor; Jodi Banowetz, art editor; Jeff Storm, designer; Sarah Lane, copy editor; and Marla Irion, the original production editor on the project. Our special appreciation goes to Marilyn Sulzer, who as project manager was instrumental in coordinating the many complexities of the publishing process and in meeting the highest standards for accuracy and quality.

We hope very much that this text will be interesting and educational for students and a help to their instructors. We would appreciate any comments and suggestions from our readers.

E. W. N.
 C. E. R.
 N. N. P.
 D. G. A.
 M. T. N.

Department of Microbiology
 University of Washington
 Seattle, WA 98195
 gnester@u.washington.edu



BRIEF CONTENTS

part one

Life and Death of Microorganisms

- 1 Microbiology in the Biological World 2
- 2 Biochemistry of the Molecules of Life 21
- 3 Functional Anatomy of Prokaryotes and Eukaryotes 45
- 4 Dynamics of Bacterial Growth 85
- 5 Metabolism: Energy Generation and Synthesis of Small Molecules 107
- 6 Informational Macromolecules: Function, Synthesis, and Regulation of Activity 131
- 7 Bacterial Genetics 153
- 8 Microbiology and Biotechnology 182
- 9 Control of Microbial Growth 201

part two

The Microbial World

- 10 Classification and Identification of Prokaryotes 222
- 11 Prokaryotic Microorganisms: Eubacteria and Archaea 242
- 12 Eukaryotic Microorganisms: Algae, Fungi, and Protozoa 275
- 13 The Nature and Study of Viruses 297
- 14 Viruses of Animals and Plants 319

part three

Microorganisms and Humans

- 15 Nonspecific Immunity 344
- 16 Specific Immunity 359
- 17 Functions and Applications of Immune Responses 378
- 18 Immunologic Disorders 395
- 19 Interactions Between Microorganisms and Humans 409
- 20 Epidemiology and Public Health 428
- 21 Antimicrobial Medicine 447
- 22 Skin Infections 471
- 23 Upper Respiratory System Infections 501
- 24 Lower Respiratory System Infections 524
- 25 Upper Alimentary System Infections 551
- 26 Lower Alimentary System Infections 568
- 27 Genitourinary Infections 599
- 28 Nervous System Infections 626
- 29 Wound Infections 651
- 30 Blood and Lymphatic Infections 672
- 31 HIV Disease and Complications of Immunodeficiency 695

part four

Applied Microbiology

- 32 Environmental Microbiology 722
- 33 Water and Waste Treatment 743
- 34 Microbiology of Food and Beverages 760

CONTENTS

Preface xxv



Life and Death of Microorganisms

chapter one

Microbiology in the Biological World 2

Key Concepts	2
A Glimpse of History	3
Microorganisms Discovered	3
The Theory of Spontaneous Generation Was Revived with the Discovery of the Microbial World	4
Perspective 1.1: Microbial Sleuthing	4
Medical Microbiology—Past Triumphs	7
Medical Microbiology—Future Challenges	7
Beneficial Applications of Microbiology—Past and Present	8
Biotechnology—New Applications for Microorganisms	8
Perspective 1.2: Cleaning Up the Environment with Bacterial Pac-Men	9
Review Questions	9
Cell Theory	9
Similarity in Function and Composition of All Cells	10
Basic Cell Types	10
Perspective 1.3: Prokaryotes and Eukaryotes in the <i>Guinness Book of Records</i>	12
Some Cell Types Appear to Be Intermediate Between Prokaryotes and Eukaryotes	12
Prokaryotes Can Be Divided into Two Major Groups Termed <i>Domains</i> —the Eubacteria and the Archaea	13
Eubacteria Comprise Most Prokaryotes Familiar to Microbiologists	13
Archaea Often Grow Under Extreme Conditions of Temperature and Salinity	14
Review Questions	15

Members of the Microbial World	15
Algae, Fungi, and Protozoa Are Eukaryotic Members of the Microbial World	15
Viruses, Viroids, and Prions Are Nonliving Members of the Microbial World	16
Sizes of Members of the Microbial World	16
Nomenclature of Organisms	16
Chapter Review Questions	19
Summary	19
Critical Thinking Questions	20
Further Reading	20

chapter two

Biochemistry of the Molecules of Life 21

Key Concepts	21
A Glimpse of History	22
Elements and Atoms	23
Formation of Molecules: Chemical Bonds	23
Perspective 2.1: Isotopes—Valuable Tools for the Study of Biological Systems	24
Covalent Bonds Are Formed When Atoms Share Electrons	24
Ionic Bonds Are Formed by the Loss and Gain of Electrons Between Atoms	26
Hydrogen Bonds Are Weak but Biologically Very Important	26
Perspective 2.2: Water—The Universal Requirement for Life	27
Review Questions	28
Important Molecules of Life	28
Small Molecules in the Cell Include a Variety of Inorganic and Organic Compounds	28
All Very Large Molecules in the Cell (Macromolecules) Consist of Repeating Subunits Called <i>Monomers</i>	30
Amino Acids Joined Together Make Up Proteins	30
Perspective 2.3: Alzheimer's Disease—A Result of Protein Misfolding?	34
Polysaccharides Are Polymers of Monosaccharide Subunits	35

Nucleic Acids Are Polymers of Nucleotide Subunits	37
Lipids Are Heterogeneous in Structure but All Are Insoluble in Water	38
Review Questions	42
Summary	43
Critical Thinking Questions	44
Further Reading	44

chapter three

Functional Anatomy of Prokaryotes and Eukaryotes 45

Key Concepts	45
A Glimpse of History	46
Microscopic Techniques: Instruments	46
The Compound Microscope Has Two Sets of Magnifying Lenses	46
The Contrast Between Cells and Their Surrounding Media Must Be Increased for Good Observations	47
Dark-field Microscopy Highlights Specimens Against a Dark Background	48
Fluorescence Microscopy Is Used to Examine Materials that Fluoresce	48
The Electron Microscope Can Resolve Objects a Thousand Times Better than the Light Microscope	48
Scanning Electron Microscopes Allow a Three-dimensional View of Objects	50
The Scanning Tunneling Microscope Can Observe Individual Atoms on the Surface of Samples	50
Microscopic Techniques: Staining	50
Simple Staining Procedures Involve a Single Dye	51
Differential Stains Distinguish Various Kinds of Bacteria Because of Differences in Their Surface Structures	51
Review Questions	53
Shapes of Bacteria	53
Functions Required in Prokaryotic Cells	54
Prokaryotic Cells—Microscopic Appearance	54
Enclosure of the Cytoplasm in Prokaryotic Cells	54
The Capsule or Slime Layer Is a Gelatinous Structure that Can Attach Bacteria to Surfaces	56
The Bacterial Cell Wall Is Rigid and Is Composed of Unique Chemical Structures	57
Review Questions	62
The Cytoplasmic Membrane Is Flexible and Is Composed of a Lipid Bilayer in All Cells	63
Movement of Prokaryotic Cells	66
Flagella Have a Relatively Simple Structure in Bacteria	66

Attachment of Prokaryotic Cells	70
Pili Are Protein Appendages of Attachment	70
Review Questions	70
Storage of Genetic Information in Prokaryotic Cells	71
The Bacterial Chromosome Is a Double-stranded, Circular DNA Molecule	71
Perspective 3.1: Plasmids, Pasteur, and Anthrax	72
Plasmids Are Small DNA Molecules that Code for Nonessential Information	72
Synthesis of Protein in Prokaryotic Cells	72
Ribosomes Are Workbenches on Which Proteins Are Synthesized	72
Storage Materials in Prokaryotic Cells	73
Endospores in Prokaryotic Cells	74
Endospores Develop from Vegetative Cells when They Face Starvation	74
Endospores Can Develop into Vegetative Cells	75
Endospores Have Unusual Staining and Resistance Properties	75
Perspective 3.2: Ancient Microbes	76
Many Endospore-producing Bacteria Cause Disease	76
Review Questions	76
The Structure of Eukaryotic Cells	77
Enclosure of the Cytoplasm in Eukaryotic Cells	78
The Cytoplasmic Membrane is the Outer Layer in Many Eukaryotic Cells	78
Internal Membrane Structures in Eukaryotic Cells	78
Several Membrane-enclosed Structures Are Involved in Biosynthesis and Transport	78
Certain Membrane-enclosed Structures Are Involved in the Degradation of Molecules	79
Shapes of Eukaryotic Cells	79
Cell Movement	79
Generation of Energy in Eukaryotic Cells	80
Energy Is Generated by Mitochondria	80
Storage of Genetic Information in Eukaryotic Cells	81
Summary	82
Critical Thinking Questions	84
Further Reading	84

chapter four

Dynamics of Bacterial Growth 85

Key Concepts	85
A Glimpse of History	86
Pure Culture Methods	86

Measurement of Cell Growth	88
Bacterial Growth Is Defined in Terms of Population Size	88
Growth Can Be Measured as an Increase in Mass (Weight) of the Population	89
Growth Can Be Measured as an Increase in Cell Number	89
Review Questions	90
Multiplication of Microorganisms—General Aspects	90
Factors Influencing Microbial Growth	90
The Environmental Factors that Influence Growth Include Temperature, Oxygen, pH, and Osmotic Pressure	90
Review Questions	95
Nutritional Aspects of Bacterial Growth	95
Cell Multiplication Requires a Source of Energy and Raw Material for Synthesis of Cell Components	95
Cultivation of Bacteria in the Laboratory	96
The Two Kinds of Media on Which Bacteria Are Grown Are Synthetic (Defined) and Complex (Undefined)	96
Perspective 4.1: Can Bacteria Live on Only Rocks and Water?	97
Anaerobes Require Special Cultivation Methods	98
Cultivation of Organisms that Occur as a Minor Part of the Microbial Population	99
Enrichment Cultures Enhance the Growth of Specific Organisms	99
Selective Media Preferentially Inhibit the Growth of Certain Organisms	99
Differential Media Serve as Useful Diagnostic Aids	100
Dynamics of Bacterial Population Growth	101
The Lag Phase of Growth Involves No Increase in Cell Numbers	101
Perspective 4.2: Bismuth Subsalicylate—A Medicine with Magical Properties	102
The Exponential Phase of Growth Results in an Exponential Increase in Cell Number	102
The Stationary Phase Is Reached when the Number of Viable Cells Stops Increasing	102
Secondary Metabolites Are Synthesized at the End of the Log Phase of Growth	103
The Death Phase Is Characterized by an Exponential Decrease in the Number of Viable Cells	103
Growth of a Bacterial Colony	103
Growth of Bacteria in Nature—An Open System	103
Microorganisms Commonly Grow in Communities in Nature	104
Summary	104
Chapter Review Questions	105
Critical Thinking Questions	106
Further Reading	106

chapter five	
Metabolism: Energy Generation and Synthesis of Small Molecules	107
Key Concepts	107
A Glimpse of History	108
Enzymes—Chemical Kinetics and Mechanisms of Action	108
Perspective 5.1: Taking Enzymes to the Cleaners	109
Enzymes Speed Up Reactions by Lowering Their Activation Energy	109
The Substrate Fits the Shape of the Enzyme that Acts on It	109
Some Enzymes Require Coenzymes for Their Function	110
Environmental and Chemical Factors Influence Enzyme Activity	111
Names of Enzymes Usually End in -ase	112
Overview of Metabolism	113
Generation of Energy—General Principles	114
Coenzymes Are Important for the Generation of Energy and the Storage of Reducing Power	114
Aerobic Respiration Involves Oxygen as a Final Hydrogen Acceptor	116
Fermentation Involves an Organic Molecule as the H Acceptor	116
Catabolic Pathways—Overview	116
Glycolysis Is the Most Common Pathway for Degrading Sugars	117
Review Questions	120
The TCA Cycle Oxidizes Pyruvic Acid to CO ₂ and H ₂ O and Traps the Energy of Pyruvic Acid in ATP	120
Much More Energy Is Gained in Respiration Than In Fermentation	122
Synthesis of ATP and Precursor Metabolites Depend on the Environment	122
Respiration Under Anaerobic Conditions	122
The Pentose Phosphate Pathway	122
Perspective 5.2: Plastics, Landfills, and Bacteria	124
Another Pathway of Glucose Degradation—the Entner-Doudoroff Pathway	124
Metabolism of Compounds Other than Glucose	124
Oxidation of Inorganic Compounds	124
Many Amino Acids Are Synthesized from the Same Precursor Metabolites	125
Perspective 5.3: Mining with Microbes	126
Purines and Pyrimidines Are Synthesized Stepwise Along Different Pathways	126
Bacterial Photosynthesis	127

Light Energy Absorbed by Chlorophyll Provides Energy to Reduce CO ₂ to Cell Material	127
Compounds Other than H ₂ O Serve as the Reducing Agents in Photosynthetic Bacteria Other than Cyanobacteria	127
Photosynthesis Requires Light for Energy Generation but Biosynthetic Reactions Do Not	127
Summary	129
Chapter Review Questions	130
Critical Thinking Questions	130
Further Reading	130

chapter six

Informational Macromolecules: Function, Synthesis, and Regulation of Activity 131

Key Concepts	131
A Glimpse of History	132
Chemistry of DNA and RNA	132
DNA Is a Double-stranded, Helical Molecule	132
The Two Strands of DNA Are Oriented in Opposite Directions	133
RNA Is Usually Single-stranded and Not as Long as DNA	133
Information Storage and Transfer—Overview	133
DNA Replication Begins at a Specific Site on the Bacterial Chromosome and Proceeds by the Sequential Addition of Nucleotides	134
The Expression of Genes	136
The Sequence of Three Nucleotides in mRNA Determines a Specific Amino Acid	136
The First Step in Gene Expression Is Making an RNA Copy of the Genetic Information in DNA	137
The Second Step in Gene Expression Is the Translation of mRNA into Protein	138
Differences Between Prokaryotic and Eukaryotic Gene Transcription/Translation	140
Perspective 6.1: Wonder Foods and Virus Resistance	141
Perspective 6.2: RNA—The First Macromolecule?	142
Review Questions	143
The Environment and Control Systems—Overview	143
Mechanisms of Control of Biosynthetic Pathways—Overview	143
End Product Repression Controls the Start of Gene Transcription	144
End Products Control the Activity of the First Enzyme of the Pathway Through Allosteric Control	145
Mechanisms of Control of Degradative Pathways	145

Metabolites that Can Be Degraded Activate the Genes Responsible for Their Degradation	145
Catabolite Repression Ensures Efficient Use of Available Foodstuffs	147
Summary	150
Chapter Review Questions	151
Critical Thinking Questions	151
Further Reading	152

chapter seven

Bacterial Genetics 153

Key Concepts	153
A Glimpse of History	154
Sources of Diversity in Microorganisms	155
Gene Alterations—Mutations	155
Mutations Can Occur by Substitution of One Base for Another	155
Mutations Can Occur by the Removal or Addition of Nucleotides	155
Mutagenesis	156
Chemical Mutagens Often Act by Altering the Hydrogen-bonding Properties of the Nitrogenous Bases	157
Transposable Elements (Jumping Genes)	157
Perspective 7.1: Barbara McClintock: The Discoverer of Jumping Genes	159
Ultraviolet Irradiation	160
Repair of Damaged DNA	160
Visible Light Activates an Enzyme that Breaks Covalent Bonds Forming Thymine Dimers	160
Bacteria Can Excise Damaged DNA and Replace It with Undamaged DNA	161
Misincorporated Bases Can Be Removed by a Proofreading Function of DNA Polymerase	162
Misincorporated Bases Can Be Removed by a Mismatch Repair System	162
UV and Chemical Damage Can Be Overcome by an Inducible Enzyme System of DNA Replication that Makes Many Mistakes	162
Mutations and Their Consequences	163
Mutations Are Expressed Rapidly in Prokaryotic Cells	164
Mutant Selection	164
Direct Selection Requires that the Mutant Grow on a Medium on Which the Parent Cannot	164
Indirect Selection Must Be Used to Isolate Mutants that Cannot Grow on a Medium on Which the Parent Can Grow	164
Conditional Lethal Mutants	166
Chemicals Can Be Tested for Their Cancer-causing Ability by Their Mutagenic Activity	166

Review Questions	166
Mechanism of Gene Transfer—General Aspects	167
Gene Transfer Between Bacteria	167
DNA-mediated Transformation Involves the Transfer of Naked DNA from Donor Cells to Recipient Cells	168
Transduction Involves Viral Transfer of DNA	169
Conjugation Requires Cell-to-cell Contact	170
Review Questions	174
Plasmids	174
Perspective 7.2: Bacteria Can Conjugate with Plants	175
R Factor Plasmids Confer Resistance to a Large Number of Antimicrobial Agents	176
Perspective 7.3: Do Dental Fillings Contribute to Antibiotic Resistance in Bacteria?	177
Gene Movement Within the Same Bacterium—Transposable Elements	177
Transposable Elements Are Important for the Transfer of Genes to Unrelated Bacteria	178
Restriction and Modification of DNA	178
Modification Enzymes Confer Resistance to Restriction Enzymes	178
Importance of Gene Transfer to Bacteria	179
Summary	179
Chapter Review Questions	181
Critical Thinking Questions	181
Further Reading	181

chapter eight

Microbiology and Biotechnology 182

Key Concepts	182
A Glimpse of History	183
Applications of Biotechnology	183
Medically Important Proteins Can Be Produced by <i>E. Coli</i> and Yeast	184
Safer Vaccines Can be Made Using Genetic Engineering	185
Bioremediation Involves the Use of Microorganisms to Degrade Harmful Chemicals	185
Plants Can Be Genetically Engineered to Develop New Properties	185
Toxins from Bacteria Can Serve as Effective Biocontrol Agents	185
Review Questions	186
Cloning	186
The Cells Are Lysed to Release All of Their DNA	188
Restriction Enzymes and DNA Ligase Are the Tools of Molecular Biology	188
Vectors Act As Self-Replicating Carriers of Foreign DNA	188

Ligating the Vector and the Insert Together Creates a Recombinant Plasmid	191
The Recombinant Plasmid Must Be Introduced into a New Host	191
Cells that Contain the Recombinant Clone Must Be Identified	192
Successful Genetic Engineering Generally Requires Gene Expression	193
In Plant Genetic Engineering, Genes Are Introduced into Plant Cells by <i>Agrobacterium</i>	194
Southern Blot	195
The DNA Must Be First Digested and then the Fragments Separated According to Size	196
The DNA Is Denatured and then Transferred to a Durable Membrane Support	196
Complementary Sequences Are Identified by Hybridizing a Probe	197
Polymerase Chain Reaction	197
Perspective 8.1: Science Takes the Witness Stand	198
Repeated Temperature Cycles Amplify the Target DNA	199
Review Questions	199
Summary	199
Chapter Review Questions	200
Critical Thinking Questions	200
Further Reading	200

chapter nine

Control of Microbial Growth 201

Key Concepts	201
A Glimpse of History	202
Approaches to Control	202
Principles Involved in Killing or Inhibiting Microorganisms	202
Using Heat to Kill Microorganisms and Viruses	203
Perspective 9.1: Some Materials Can Be Sterilized by Temperatures Below Boiling	204
Dry Heat Requires More Time than Wet Heat to Kill Microorganisms	204
Boiling Kills Most Vegetative Cells But Not Bacterial Endospores	204
Pressure Cookers and Autoclaves Are Effective Sterilizers	204
The Commercial Food-Canning Process	206
Pasteurization Eliminates Most Pathogens and Reduces the Number of Spoilage Organisms	207
Sterilization by Filtration	208
Membrane Filters Have Multiple Uses	208
Chemicals Used for Sterilization, Disinfection, and Preservation	209

The Germicidal Activity of Chemicals Can Be Ranked	209
Review Questions	210
Germicidal Chemicals Used in Medical Fields Are Federally Regulated	210
A Number of Chemical Families Provide Useful Germicides	211
Perspective 9.2: Formaldehyde Pollution of Household Air	213
Perspective 9.3: Contamination of an Operating Room by a Bacterial Pathogen	214
Perspective 9.4: Mercury Poisoning from Latex Paint	215
Radiation	215
Gamma Rays Cause Biological Damage by Producing Hyperreactive Ions	215
Perspective 9.5: Disinfection of Spilled Blood	216
Ultraviolet Radiation Damages Nucleic Acids	216
Microwaves Do Not Kill Organisms Directly	216
Preservation	216
Perspective 9.6: Comparison of Sterilizing and Disinfecting Techniques	217
Chemicals Are Used as Preservatives	217
Growth of Spoilage Microorganisms Is Slowed or Halted by Low-temperature Treatment	218
Desiccation (Drying) or Adding Sugar and Salt Prevent Microbial Growth by Reducing the Water Activity	218
Review Questions	218
Technique 9.1: Using an Autoclave	219
Summary	219
Chapter Review Questions	220
Critical Thinking Questions	220
Further Reading	220



The Microbial World

chapter ten Classification and Identification of Prokaryotes 222

Key Concepts	222
A Glimpse of History	223
Problems in Classifying Microorganisms	223

Present-Day Classification Schemes	224
Numerical Taxonomy	224
Molecular Approaches to Taxonomy	225
DNA Base Compositions of Organisms Indicate Whether or Not They May Be Related	225
Comparing Sequence of Bases in DNA Determines How Closely Organisms Are Related to One Another	226
Amino Acid Sequence Similarities in the Same Protein Can Indicate Relatedness Between Organisms	228
Determination of the Base Sequences in 16S Ribosomal RNA Reveals Evolutionary Relationships Between Diverse Groups of Bacteria	228
Perspective 10.1: Surprising Relationships	230
Perspective 10.2: Captures and More Captures	231
Review Questions	231
Methods of Identifying Bacteria	232
Direct Methods of Identification Involve Microscopic Examination Without Culturing the Organisms	232
Cultivation Techniques Involve Growing the Unknown Organisms in Pure Culture	234
Products of Metabolism May Be Detectable Before Visible Growth of a Microorganism	234
Molecular Approaches in Diagnostic Microbiology Usually Involve Analysis of DNA	235
Perspective 10.3: <i>Escherichia coli</i>, Unpasteurized Apple Juice, and a Serious Disease Outbreak	237
Microorganisms that Cannot Be Cultivated Can Still Be Identified	238
Infectious Agents Present in Extremely Small Numbers Can Be Identified	239
Summary	240
Chapter Review Questions	241
Critical Thinking Questions	241
Further Reading	241

chapter eleven Prokaryotic Microorganisms: Eubacteria and Archaea 242

Key Concepts	242
A Glimpse of History	243
Prokaryotes with a Gram-Negative Type of Cell Wall	243
The Spirochetes Have a Distinctive Shape and Unusual Mechanism of Motility	243
The Aerobic Motile, Helical, or Comma-Shaped Gram-Negative Bacteria Have Rigid Cell Walls and Flagella	244

Gram-Negative Aerobic Rods and Cocci Represent a Large and Diverse Group of Prokaryotes	246	Prokaryotes Whose Cell Walls Lack Peptidoglycan	267
Review Questions	248	Archaea Differ from Eubacteria in Many Respects	269
Facultatively Anaerobic Gram-Negative Rods Are Represented by Enterobacteria and Vibrios	248	Review Questions	271
Most Fermentative Anaerobic Gram-Negative Straight, Curved, and Helical Rods Inhabit Animal Digestive Tracts	249	Summary	271
The Dissimilatory Sulfate- or Sulfur-Reducing Bacteria Generally Live in Mud Rich in Organic Material and Oxidized Sulfur Compounds	249	Chapter Review Questions	273
Most Rickettsias and Chlamydias Are Obligate Intracellular Parasites	250	Critical Thinking Questions	273
Review Questions	251	Further Reading	273
Endosymbionts Are Microorganisms that Have Established a Stable Intracellular Relationship with a Eukaryotic Host Cell	252	chapter twelve	
Nonphotosynthetic, Gliding Bacteria Are Widespread in the Environment and May Be Found in the Human Mouth	252	Eukaryotic Microorganisms: Algae, Fungi, and Protozoa	275
Myxobacteria Are Fruiting, Gliding Bacteria	253	Key Concepts	275
Sheathed Bacteria Are Enclosed in a Lipoprotein-Polysaccharide Material	254	A Glimpse of History	276
Anoxygenic Phototrophic Bacteria Carry on Photosynthesis Without Releasing Oxygen	254	Algae	276
Oxygenic Photosynthetic Bacteria Liberate Oxygen as a By-Product of Their Photosynthesis	255	Algae Are Classified According to Their Photosynthetic Pigments	276
Budding and/or Appendaged Bacteria Are Characterized by Cytoplasm-Filled Projections from the Main Cell Body	257	Algae Occur in a Variety of Habitats and Can Be Either Microscopic or Macroscopic	276
Many Aerobic Chemolithotrophic Bacteria Can Grow in the Dark on Media Containing Only Inorganic Substances	257	Perspective 12.1: Could the Algae Growing in the Ocean Be More Important to Global Warming than Tropical Rain Forests?	279
Review Questions	259	Algae Are Typical Eukaryotic Organisms	280
Prokaryotes with a Gram-Positive Type of Cell Wall	259	Algae Reproduce by Both Asexual and Sexual Means	280
Gram-Positive Cocci Comprise a Large Group, Subdivided on the Basis of Arrangement of Cells and Metabolic Differences	259	Some Algal Species Produce Toxins that Cause Paralytic Shellfish Poisoning	282
Only a Few Genera of Gram-Positive Rods and Cocci Are Endospore-Forming	260	Review Questions	282
Some Cylindrical Gram-Positive Rods Do Not Form Endospores	261	Fungi	282
The Irregularly Shaped, Nonspore-Forming, Gram-Positive Rods Include Many Unrelated Genera	261	Fungi Occur in Diverse Habitats	283
The Mycobacteria Demonstrate the Acid-Fast Staining Property	263	Most Fungi Are Aerobic Heterotrophic Organisms	284
Many Species of Branching, Gram-Positive Bacteria (Actinomycetes) Have Aerial and Specialized Hyphae	264	The Terms <i>Yeast</i> , <i>Molds</i> , and <i>Mushrooms</i> Are Common Names that Refer to Various Fungal Forms	284
Prokaryotes that Lack Cell Walls	266	Perspective 12.2: <i>Pneumocystis carinii</i>—Protozoan or Fungus?	285
The Mycoplasmas Are Very Small Prokaryotes Bounded Only by a Plasma Membrane	267	Classification of Fungi Is Revised Frequently	286
		Fungi Cause Disease in Humans	287
		Perspective 12.3: The Salem Witch Hunts	288
		Some Fungi Form Symbiotic Relationships with Other Organisms	288
		Fungi Are Economically Important Organisms Both for the Good They Do and the Damage They Cause	290
		Review Questions	290
		Protozoa	290
		Protozoan Habitats Are Diverse	290
		Protozoan Classification Is Based Primarily on the Presence or Absence of Organelles of Locomotion	290
		Protozoa Lack a Cell Wall	292