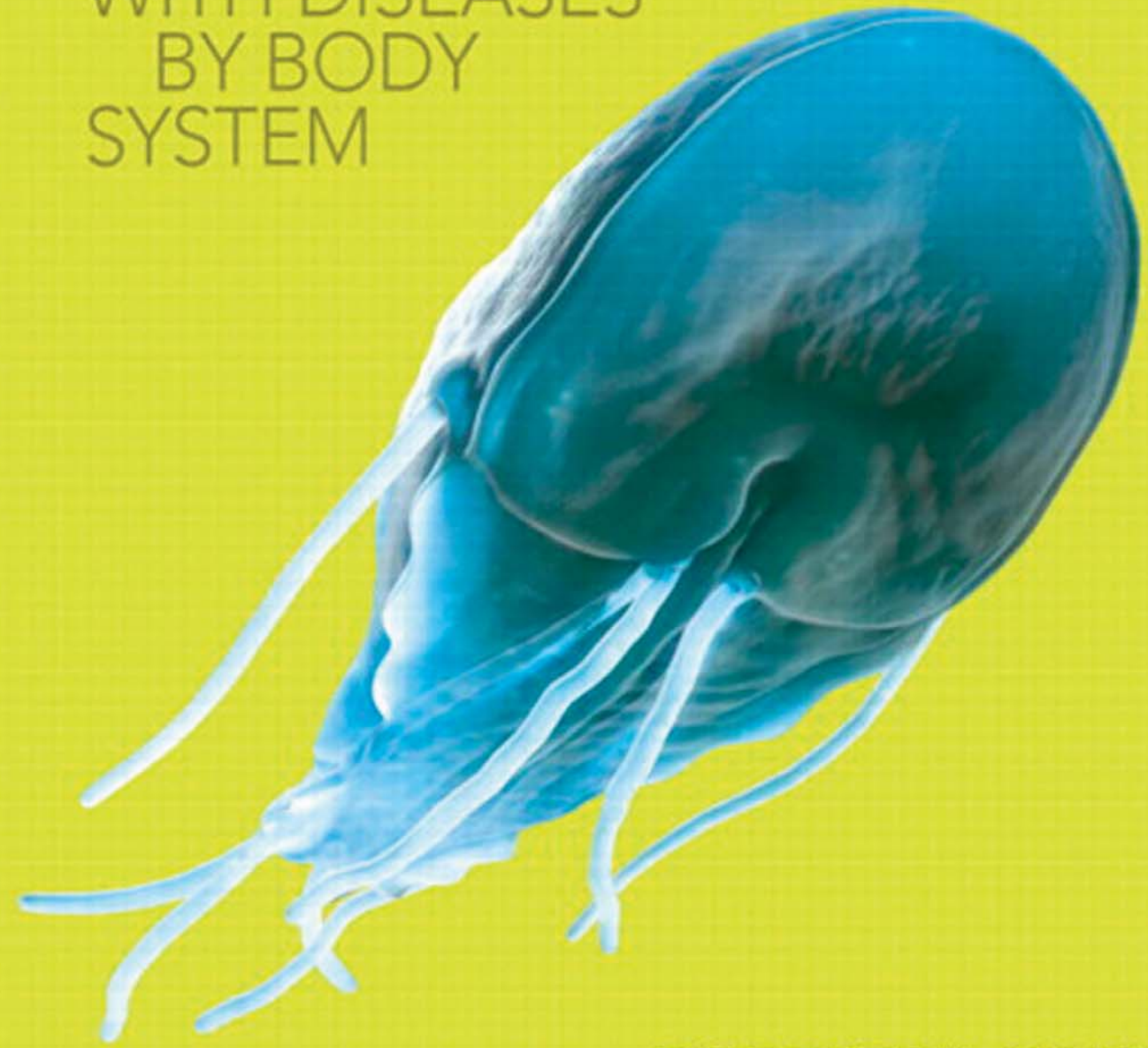
FOURTH EDITION

MICROBIOLOGY

WITH DISEASES BY BODY SYSTEM



ROBERT W. BAUMAN

Contents

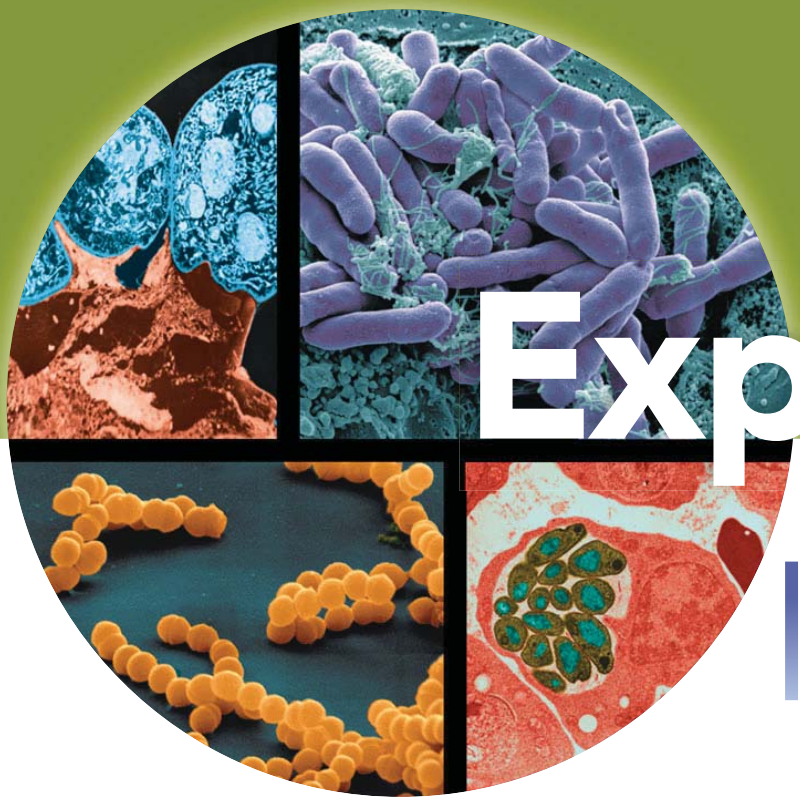
CHAPTER

VIDEO TUTORS BY CHAPTER

Scan this QR code with your smartphone for an introduction to Dr. Robert Bauman's Microbiology Video Tutors!

CHAPTER

DISEASE IN DEPTH FEATURES BY CHAPTER



Explore the Invisible

Investigate It

DISEASE IN DEPTH

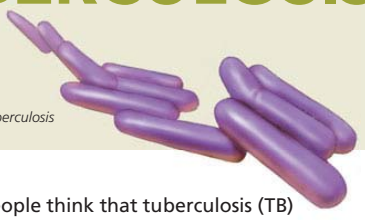
New **Disease in Depth** spreads visually tell the story of important and representative diseases for each body system, examining the history, present incidents, and potential future developments of specific diseases.

INVESTIGATE IT!

Each **Disease in Depth** feature includes a QR code and Investigate It! question that direct students to a major health website prompting further exploration and critical thinking. New MasteringMicrobiology® assignable Disease in Depth coaching activities encourage students to engage in independent research to apply and test their understanding of key concepts related to the Investigate It! query.

DISEASE IN DEPTH

TUBERCULOSIS



Mycobacterium tuberculosis

Many people think that tuberculosis (TB) is a disease of the past, one that has little importance to people living in industrialized countries. In part, this attitude results from the success health care workers have had in reducing the number of cases. Nevertheless, epidemiologists warn that complacency can allow this terrible killer to reemerge.

SIGNS AND SYMPTOMS

Signs and symptoms of TB are not always apparent, often limited to a minor cough and mild fever. Breathing difficulty, fatigue, malaise, weight loss, chest pain, wheezing, and coughing up blood characterize the disease as it progresses.

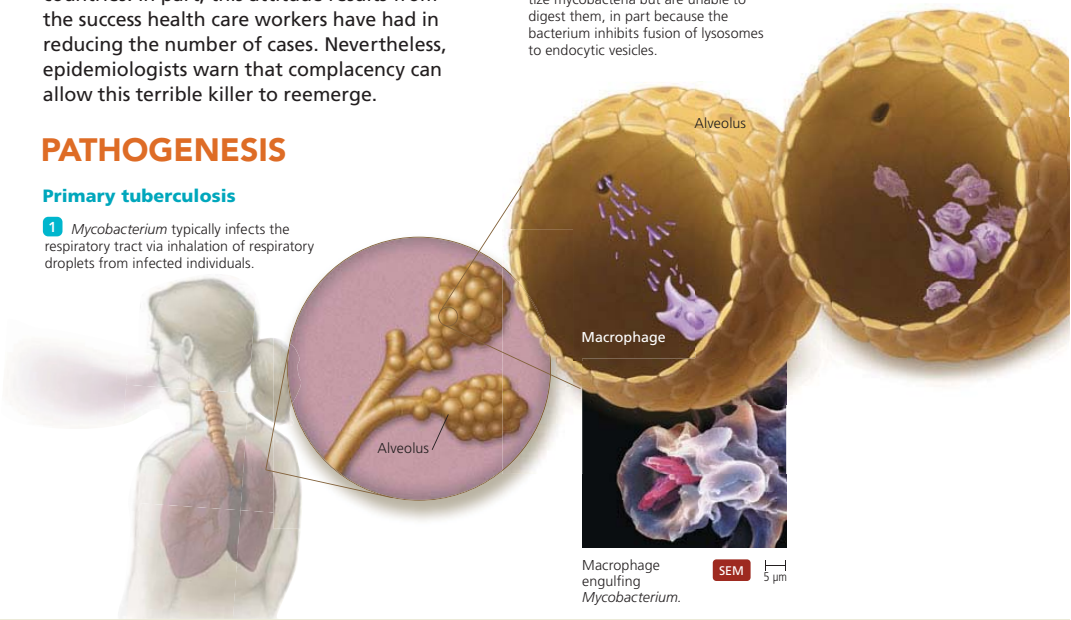
PATHOGENESIS

Primary tuberculosis

1 *Mycobacterium* typically infects the respiratory tract via inhalation of respiratory droplets from infected individuals.

2 Macrophages in alveoli phagocytize mycobacteria but are unable to digest them, in part because the bacterium inhibits fusion of lysosomes to endocytic vesicles.

3 Instead, bacteria replicate freely within macrophages, gradually killing th phagocytes. Bacteria released from dead macrophages are phagocytized by other macrophages, beginning the cycle anew



Macrophage engulfing *Mycobacterium*.

INVESTIGATE IT!

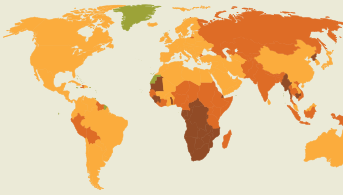
What does the development of XDR-TB (extensively drug-resistant strains of Mycobacterium tuberculosis*) portend for the future of the disease?*

Scan this code to visit the Centers for Disease Control and Prevention website to investigate XDR-TB. Then go to MasteringMicrobiology to record your research findings.

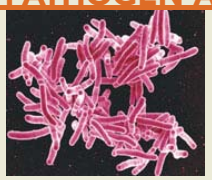
EPIDEMIOLOGY

Tuberculosis kills on average four people every minute, mostly in Asia and Africa. TB is on the decline in the U.S., though the CDC estimates that TB may still infect more than 9 million Americans. One third of the world's population is infected, and over 9 million new cases are seen each year.

Left, estimated new TB cases in 2010 per 100,000 (WHO)

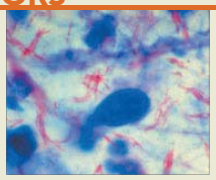


PATHOGEN AND VIRULENCE FACTORS



SEM 5 µm

Mycobacterium tuberculosis is a high G + C, aerobic, Gram-positive rod. Virulent strains produce cord factor, a cell wall component that produces strands of daughter cells that remain attached to one another in parallel alignments. Cord factor also inhibits migration of neutrophils and is toxic to mammalian cells. Multi-drug-resistant (MDR-TB) and extensively drug-resistant (XDR-TB) strains of *Mycobacterium* make it more difficult to rid the world of TB.

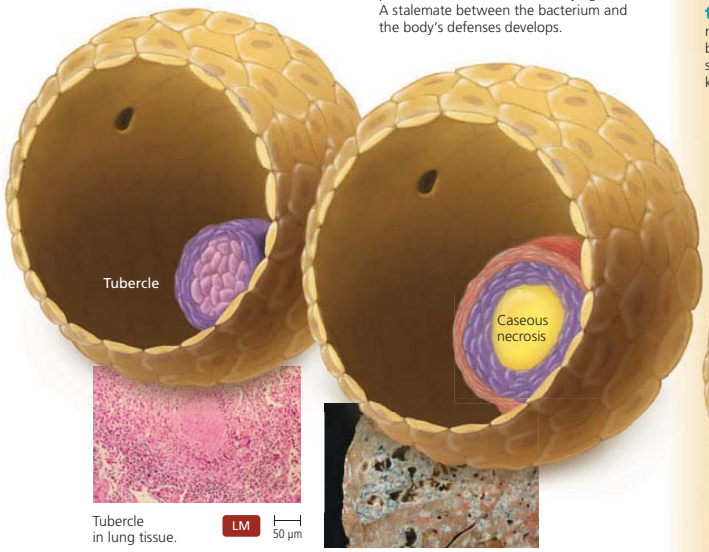


LM 15 µm

Cell walls contain mycolic acid, a waxy lipid that is responsible for unique characteristics of this pathogen, including slow growth, protection from lysis when cells are phagocytized, intracellular growth, and resistance to Gram staining, detergents, many common antimicrobial drugs, and drying out. (Slow growth is due in part to the time required to synthesize molecules of mycolic acid.)

4 Infected macrophages present antigen to T lymphocytes, which produce lymphokines that attract and activate more macrophages and trigger inflammation. Tightly packed macrophages surround the site of infection, forming a tubercle over a two- to three-month period.

5 Other cells deposit collagen fibers, enclosing infected macrophages and lung cells within the tubercle. Infected cells in the center die, releasing *M. tuberculosis* and producing caseous necrosis—the death of tissue that takes on a cheese-like consistency due to protein and fat released from dying cells. A stalemate between the bacterium and the body's defenses develops.



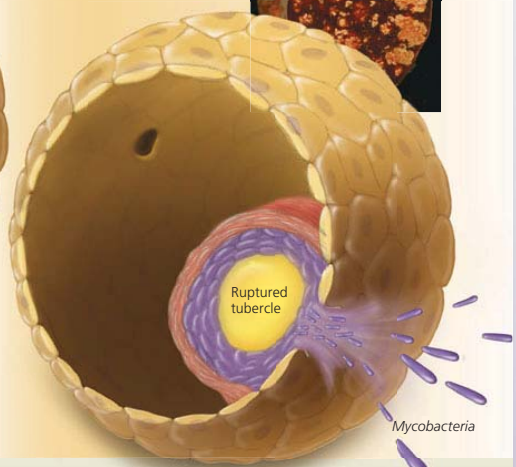
Tubercle in lung tissue. LM 50 µm

Lung lesions caused by TB.

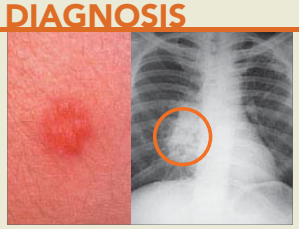
Secondary/reactivated tuberculosis results when *M. tuberculosis* breaks the stalemate, ruptures the tubercle, and reestablishes an active infection. Reactivation occurs in about 10% of patients; patients whose immune systems are weakened by disease, poor nutrition, drug or alcohol abuse, or by other factors.

Disseminated tuberculosis results when macrophages carry the pathogen via blood and lymph nodes to other sites, including bone marrow, spleen, kidneys, spinal cord, and brain.

Tuberculosis lesions in spleen.



DIAGNOSIS



10 mm

A tuberculin skin test is used to screen patients for TB exposure. A positive reaction is an enlarged, reddened, and raised lesion at the inoculation site. Chest X-ray films can reveal the presence of tubercles in the lungs. Primary TB usually occurs in the lower and central areas of the lung; secondary TB commonly appears higher.

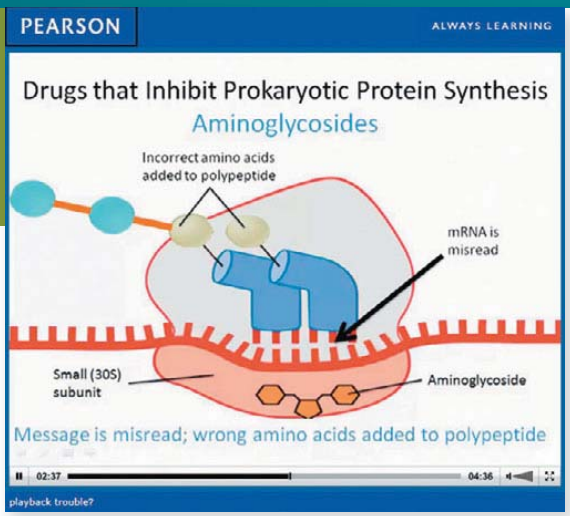
TREATMENT AND PREVENTION

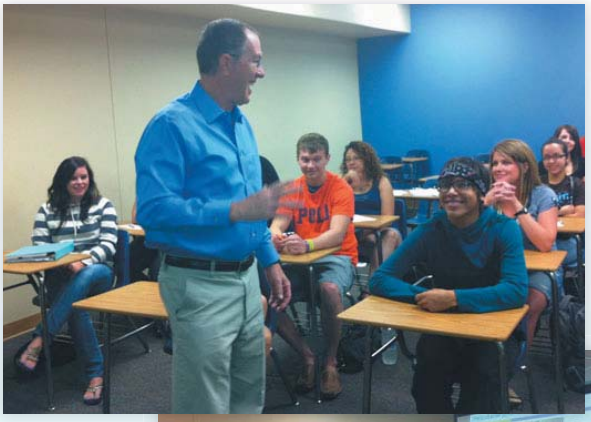
Treatment combines isoniazid, rifampin, and one of several drugs (such as ethambutol, levofloxacin, or streptomycin) for six months. Newly approved bedaquiline is used in combination with other drugs to treat MDR-TB or XDR-TB. In countries where TB is common, health care workers immunize patients with BCG vaccine, which is not recommended for the immunocompromised because it can cause disease. Workers must avoid inhaling respiratory droplets from TB patients.

Make the Invisible Visible

NEW! 18 VIDEO TUTORS

Developed for the Fourth Edition and accessible via QR codes in the text and the student Study Area in MasteringMicrobiology®, new **Video Tutors** by Dr. Robert W. Bauman help students explore important processes and tough topics. These tutorials engage students as they visualize and learn key concepts in microbiology, bringing the textbook art to life. These video tutorials also include assignable multiple-choice questions in MasteringMicrobiology.





VIDEO TUTOR TOPICS

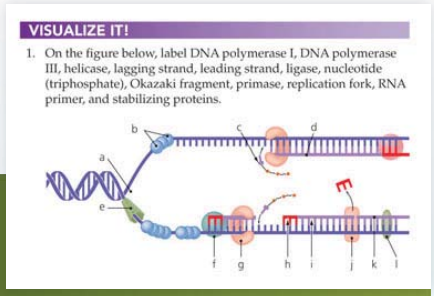
- The Scientific Method
- The Structure of Nucleotides
- Bacterial Cell Walls
- The Light Microscope
- Electron Transport Chains
- Bacterial Growth Media
- Initiation of Translation
- Action of Restriction Enzymes
- Principles of Autoclaving
- Actions of Some Drugs that Inhibit Prokaryotic Protein Synthesis
- Arrangements of Prokaryotic Cells
- Principles of Sexual Reproduction in Fungi
- The Lytic Cycle of Viral Replication
- Some Virulence Factors
- Inflammation
- Clonal Deletion
- ELISA
- Hemolytic Disease of the Newborn

AMERICAN SOCIETY FOR MICROBIOLOGY

NEW! **Tell Me Why Critical Thinking Questions** end all A-head sections. These questions strengthen the pedagogy and organization of each chapter and consistently provide stop-and-think opportunities for students as they read.

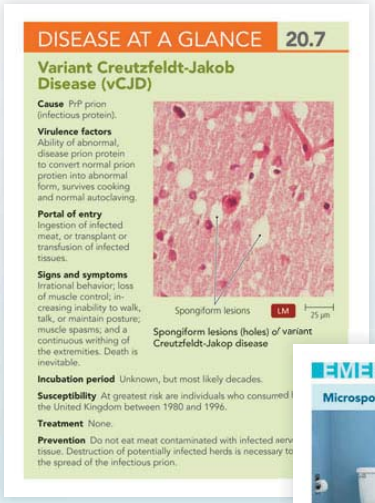
NEW! **Numbered Learning Outcomes** in the textbook are used to tag Test Bank questions and all Mastering assets. In addition to being tagged to Learning Outcomes, Mastering assessments are tagged to the Global Science Learning Outcomes and Bloom's Taxonomy. The complete Mastering Test Bank is also tagged to ASMCUE recommended outcomes.

NEW! **Expanded Coverage of Helminthes** is provided in new highlight features, and an emphasis on virulence factors is showcased where appropriate in the Fourth Edition's Disease at a Glance and Disease in Depth features.

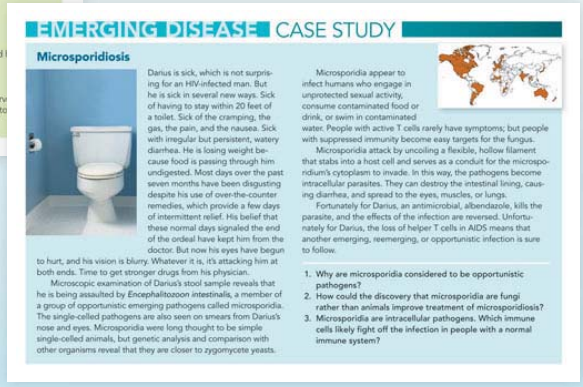


NEW! **VISUALIZE IT!**

Appearing at the end of each chapter, these short-answer or fill-in-the-blank questions are built around illustrations or photos. Visualize It! questions are also assignable as art labeling activities in MasteringMicrobiology.



Additional **Disease at a Glance** features provide more extensive disease coverage.

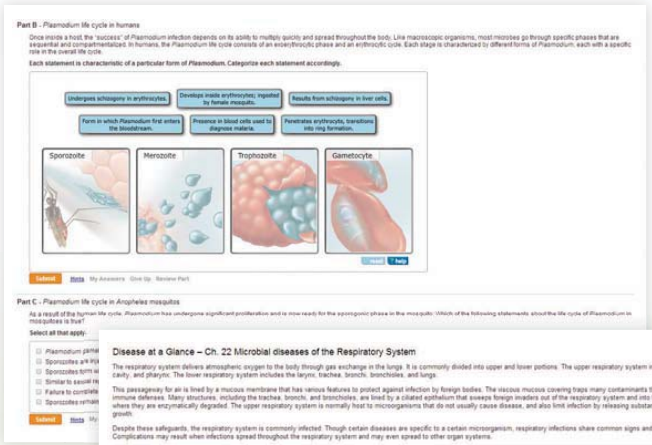


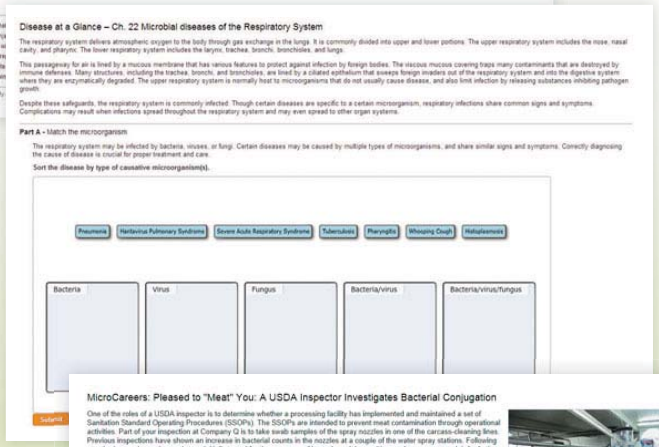
NEW! **Critical Thinking Questions** in **Emerging Disease Case Studies** allow students to delve deeper into each case.

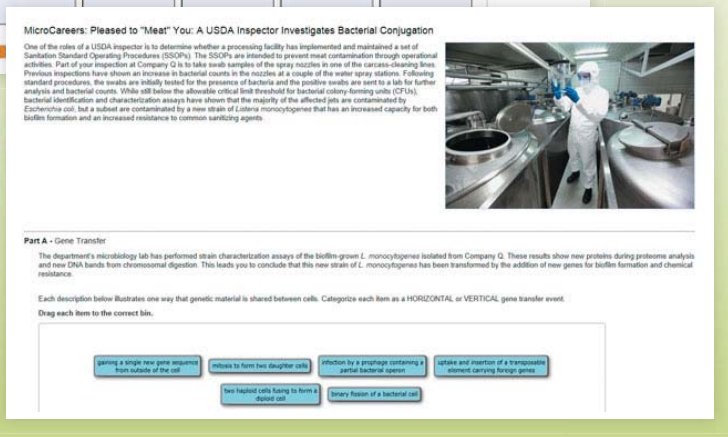
Fostering Engagement and Adaptive Learning

Dynamic, Interactive Learning

MasteringMicrobiology® guides students through microbiology topics with assignable, self-paced activities that provide individualized coaching and feedback specific to each student's misconceptions. **www.masteringmicrobiology.com**







NEW!

DISEASE IN DEPTH COACHING ACTIVITIES

Each **Disease in Depth** feature from the book corresponds to an assignable Mastering Coaching activity.

NEW!

DISEASE AT A GLANCE COACHING ACTIVITIES

These activities require students to recognize and sort diseases by different categories (transmission type, pathogenesis, signs and symptoms, associated organisms, treatment, etc.).

NEW!

MICROCAREERS COACHING ACTIVITIES

Students will learn to think like microbiologists with new MicroCareers coaching activities. These activities offer new opportunities to investigate emerging diseases from different career perspectives and think critically to solve microbiology-related questions.

CLINICAL CASE STUDY COACHING ACTIVITIES

These activities in MasteringMicrobiology help students connect microbiological theory to real-world disease diagnosis and treatment; they are assignable, and feed directly into the MasteringMicrobiology gradebook.

MICROLAB TUTORS

Helping students get the most out of lab time, each MicroLab Tutor begins with clinical background and a technique video. Select MicroLab Tutors include visually stunning molecular animations, encouraging students to visualize the processes at a molecular level. All 13 Tutors include photomicrographs and video or animation clip hints and feedback designed to assess understanding of lab concepts and techniques outside of formal lecture and lab time.

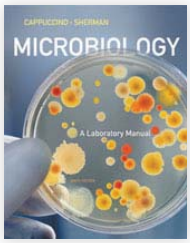
DYNAMIC STUDY MODULES

MasteringMicrobiology's Dynamic Study Modules, powered by Amplifire, boost knowledge acquisition and retention, fostering more effective study and class time and allowing students to come to class better prepared and ready for higher levels of learning.

LEARNING CATALYTICS

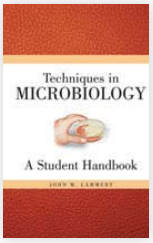
Now a part of the MasteringMicrobiology suite of powerful resources, this student engagement, assessment, and classroom intelligence system allows students to use their laptops, smartphones, or tablets to respond to questions in class. Learning Catalytics provides meaningful question types and facilitates classroom discussions and activities, supporting active learning in every classroom.

The **Best Support** for Instructors and Students



Microbiology: A Laboratory Manual
Tenth Edition
by James Cappuccino and Natalie Sherman
978-0-321-84022-6 ▪ 0-321-84022-4

Versatile, comprehensive, and clearly written, this competitively priced laboratory manual can be used with any undergraduate microbiology text—and now features brief clinical applications for each experiment, MasteringMicrobiology® quizzes that correspond to each experiment, and a new experiment on hand washing. *Microbiology: A Laboratory Manual* is known for its thorough coverage, descriptive and straightforward procedures, and minimal equipment requirements.



Techniques in Microbiology: A Student Handbook
by John M. Lammert | 978-0-132-24011-6 ▪ 0-132-24011-4

Lammert's approach is visual and incorporates "voice balloons" that keep the student focused on the process described. The techniques are those that will be used frequently for studying microbes in the laboratory, and include those identified by the American Society for Microbiology in its recommendations for the Microbiology Laboratory Core Curriculum.

ALSO AVAILABLE TO HELP YOUR STUDENTS FOR LAB:

Laboratory Experiments in Microbiology Tenth Edition
by Ted R. Johnson and Christine L. Case | 978-0-321-79438-3 ▪ 0-321-79438-9

ADDITIONAL SUPPLEMENTS

FOR INSTRUCTORS

Instructor's Resource DVD
978-0-321-94986-8 ▪ 0-321-94986-2

The Instructor's Resource DVD offers a wealth of instructor media resources, including presentation art, lecture outlines, test items, and answer keys—all in one convenient location. These resources help instructors prepare for class—and create dynamic lectures—in half the time! The IR-DVD includes:

- All figures from the book with and without labels in both JPEG and PowerPoint® formats
- All figures from the book with the Label Edit feature in PowerPoint format
- Select "process" figures from the book with the Step Edit feature in PowerPoint format
- All tables from the book
- Lab Technique Videos, MicroLab Tutors, BioFlix® and MicroFlix™ Animations, Microbiology Animations, and Microbiology Videos
- PowerPoint lecture outlines, including figures and tables from the book and links to the animations and videos
- Clicker Questions
- Quiz Show Questions
- PDF files of Transparency Acetate masters
- The Instructor's Manual as editable Microsoft® Word files
- The Instructor's Manual in PDF format
- The Test Bank as editable Microsoft Word files
- The Test Bank in TestGen® format
- The Instructor's Guide for Cappuccino/Sherman, *Microbiology: A Laboratory Manual*, Tenth Edition in PDF format
- The Preparation Guide for Johnson/Case, *Laboratory Experiments in Microbiology*, Tenth Edition in PDF format

Instructor's Manual / Test Bank
by Nichol Dolby
978-0-321-94984-4 ▪ 0-321-94984-6

This printed guide includes a chapter outline and a detailed chapter summary for each chapter as well as answers to in-text Clinical Case Studies, in-text Critical Thinking questions, and End-of-Chapter Review questions. Each test item in the printed Test Bank has been tagged with its corresponding section title from the textbook as well as book-specific Learning Outcomes and a Bloom's Taxonomy ranking (Knowledge, Comprehension, Application, or Analysis), allowing instructors to test students on a range of learning levels. The Test Bank has been updated with 25% new questions. This supplement is also available in Microsoft Word format on the Instructor's Resource DVD and on the Instructor Resource Center.

COURSE MANAGEMENT OPTIONS

MasteringMicrobiology®—Instant Access
www.masteringmicrobiology.com

Mastering helps instructors maximize class time with easy-to-assign, customizable, and automatically graded assessments that motivate students to learn outside class and arrive prepared for lecture or lab.

Blackboard—Instant Access
www.pearsonhighered.com/elearning

This open-access course management system includes the Pre-Tests, Practice Tests, Microbiology Animations, Microbiology Videos, Microbe Reviews, Flashcards, and the Glossary from the MasteringMicrobiology Study Area (www.masteringmicrobiology.com).

FOR STUDENTS

MasteringMicrobiology® with Pearson eText—Standalone Access Card
978-0-321-95682-8 ▪ 0-321-95682-6

MasteringMicrobiology®—Instant Access
www.masteringmicrobiology.com

See "For Instructors" for full description.

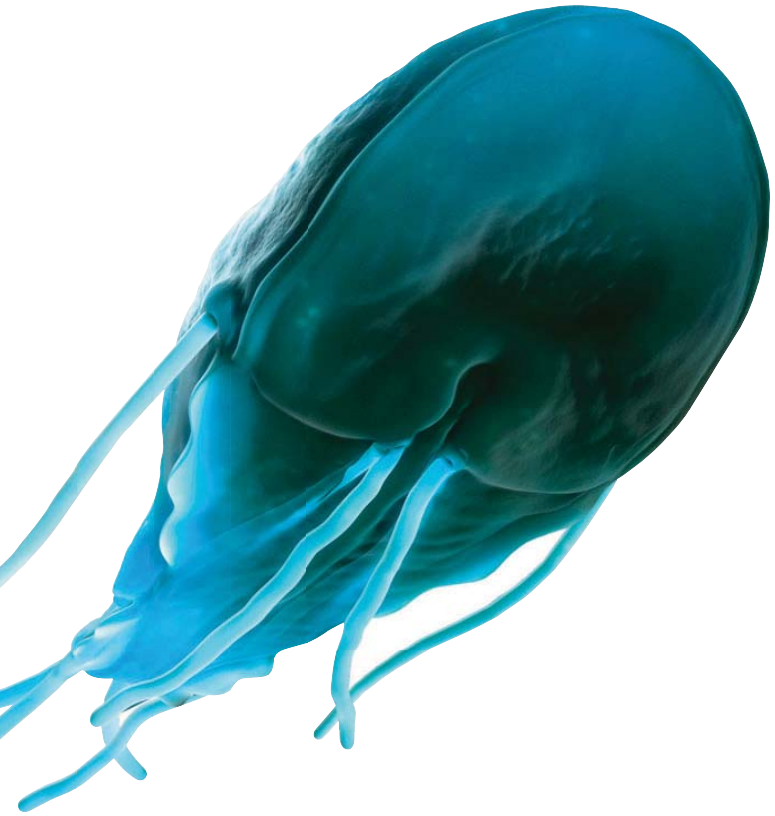
Get Ready for Microbiology Media Update
by Lori K. Garrett and Judy M. Penn
978-0-321-68347-2 ▪ 0-321-68347-1

Get Ready for Microbiology helps students quickly prepare for their microbiology course and provides useful materials for future reference. The workbook gets students up to speed with chapters on study skills, math skills, microbiology terminology, basic chemistry, basic biology, and basic cell microbiology. Each chapter includes a pre-test, guided explanations, interactive practice quizzes with answers explained, quizzes with answers given, motivations for learning, and end-of-chapter cumulative tests with answers given at the back of the book.

FOURTH EDITION

MICROBIOLOGY

WITH DISEASES BY BODY SYSTEM



ROBERT W. BAUMAN, Ph.D.
Amarillo College

CLINICAL CONSULTANTS:

Cecily D. Cosby, Ph.D., FNP-C, PA-C
Samuel Merritt College

Janet Fulks, Ed.D.
Bakersfield College

John M. Lammert, Ph.D.
Gustavus Adolphus College

CONTRIBUTIONS BY:

Elizabeth Machunis-Masuoka, Ph.D.
University of Virginia

Jean E. Montgomery, MSN, RN
Austin Community College

PEARSON

Boston Columbus Indianapolis New York
San Francisco Upper Saddle River Amsterdam
Cape Town Dubai London Madrid Milan
Munich Paris Montréal Toronto Delhi
Mexico City São Paulo Sydney Hong Kong
Seoul Singapore Taipei Tokyo

Senior Acquisitions Editor: *Kelsey Churchman*
Associate Editor: *Nicole McFadden*
Director of Development: *Barbara Yien*
Assistant Editor: *Ashley Williams*
Art Development Editor: *Kelly Murphy*
Managing Editor: *Michael Early*
Assistant Managing Editor: *Nancy Tabor*
Project Manager: *Lauren Beebe*
Director, Media Development: *Lauren Fogel*
Assistant Media Producer: *Annie Wang/Natalie Pettry*
Copyeditor: *Sally Peyerfitte*
Design Manager: *Marilyn Perry*
Interior and Cover Designer: *Elise Lansdon*
Illustration: *Precision Graphics*
Associate Director of Image Management: *Travis Amos*
Photo Researcher: *Maureen Spuhler*
Photo Permissions: *PreMedia Global*
Text Permissions Project Manager: *Michael Farmer*
Senior Procurement Specialist: *Stacey Weinberger*
Senior Marketing Manager: *Neena Bali*

Cover Photo Credit: RGB Pictures/Alamy

Credits and acknowledgments for materials borrowed from other sources and reproduced, with permission, in this textbook appear on the appropriate page or on p. CR-1.

Library of Congress Cataloging-in-Publication Data
Bauman, Robert W., author.
Microbiology: with diseases by body system/Robert W. Bauman; clinical consultants, Cecily D. Cosby, Janet Fulks, John M. Lammert ; contributions by Elizabeth Machunis-Masuoka, Jean E. Montgomery. — Fourth edition.
p. ; cm.
ISBN-13: 978-0-321-91855-0
ISBN-10: 0-321-91855-X
I. Title. [DNLM: 1. Microbiological Phenomena. 2. Communicable Diseases—microbiology. 3. Microbiological Techniques—methods. QW 4]
QR41.2
579—dc23

2013044683

ISBN 10: 0-321-91855-X (Student edition)
ISBN 13: 978-0-321-91855-0 (Student edition)
ISBN 10: 0-321-94367-8 (Instructor's Review Copy)
ISBN 13: 978-0-321-94367-5 (Instructor's Review Copy)

PEARSON

www.pearsonhighered.com

1 2 3 4 5 6 7 8 9 10—DOW—16 15 14 13

To Michelle:
My best friend, my closest confidant, my cheerleader, my partner, my love. Thirty-one years! I love you more now than then.

—Robert

About the Author

ROBERT W. BAUMAN is a professor of biology and past chairman of the Department of Biological Sciences at Amarillo College in Amarillo, Texas. He teaches microbiology, human anatomy and physiology, and botany. In 2004, the students of Amarillo College selected Dr. Bauman as the recipient of the John F. Mead Faculty Excellence Award. He received an M.A. degree in botany from the University of Texas at Austin and a Ph.D. in biology from Stanford University. His research interests have included the morphology and ecology of freshwater algae, the cell biology of marine algae (particularly the deposition of cell walls and intercellular communication), and environmentally triggered chromogenesis in butterflies. He is a member of the American Society of Microbiology (ASM) where he has held national offices, Texas Community College Teacher's Association (TCCTA), American Association for the Advancement of Science (AAAS), Human Anatomy and Physiology Society (HAPS), and The Lepidopterists' Society. When he is not writing books, he enjoys spending time with his family: gardening, hiking, camping, rock climbing, backpacking, cycling, snowshoeing, skiing, and reading by a crackling fire in the winter and a gently swaying hammock in the summer.

About the Clinical Consultants

CECILY D. COSBY is nationally certified as both a family nurse practitioner and physician assistant. She is a professor of nursing, currently teaching at Samuel Merritt University in Oakland, California, and has been in clinical practice since 1980. She received her Ph.D. and M.S. from the University of California, San Francisco; her BSN from California State University, Long Beach; and her P.A. certificate from the Stanford Primary Care program. She is the Director of Samuel Merritt University's Doctor of Nursing Practice Program.

JANET FULKS is a professor of microbiology at Bakersfield College and a clinical laboratory scientist. She received her M.A. in Biology with an emphasis in microbiology from the University of the Pacific, and her Ed.D. in higher education leadership from Nova Southeastern University. Dr. Fulks and her husband spent six years in Nepal, working with doctors to diagnose diseases and train Nepalese hospital workers. She has also worked at the CDC and at a variety of clinical microbiology labs. Dr. Fulks has taught at Bakersfield College for over 20 years. Her primary research areas are student learning outcomes and assessment, educational data literacy, student success, and educational accountability.

JOHN M. LAMMERT is a professor of biology at Gustavus Adolphus College. He teaches courses in microbiology, immunology, and introductory biology. In 1998, he received the Edgar M. Carlson Award for Distinguished Teaching at Gustavus Adolphus College, and in 2012 he was included in *Princeton Review*'s Best 300 Professors. Dr. Lammert received an M.A. in biology from Valparaiso University and a Ph.D. in immunology from the University of Illinois–Medical Center, Chicago. He is the author of *Techniques in Microbiology: A Student Handbook* and three books on science fair projects (microbes, plants, and the human body).

Preface

The spread of whooping cough, snail fever, spotted fever rickettsiosis, and other emerging diseases; the cases of strep throat, MRSA, and tuberculosis; the progress of cutting-edge research into microbial genetics; the challenge of increasingly drug-resistant pathogens; the continual discovery of microorganisms previously unknown—these are just a few examples of why exploring microbiology has never been more exciting, or more important. Welcome!

I have taught microbiology to undergraduates for over 25 years and witnessed firsthand how students struggle with the same topics and concepts year after year. To address these challenging topics, I have developed and narrated Video Tutors for the first 18 chapters and added full-spread Disease in Depth features to the next six chapters. The Video Tutors and Disease in Depth features walk students through key concepts in microbiology, bringing the art of the textbook to life and important concepts into view. In creating this textbook, my goal was to help students see complex topics of microbiology—especially metabolism, genetics, and immunology—in a way that they can understand, while at the same time presenting a thorough and accurate overview of microbiology. I also wished to highlight the many positive effects of microorganisms on our lives, along with the medically important microorganisms that cause disease.

New to This Edition

In approaching the fourth edition, my goal was to build upon the strengths and success of the previous editions by updating it with the latest scientific and educational research and data available and by incorporating the many terrific suggestions I have received from colleagues and students alike. The feedback from instructors who adopted previous editions has been immensely gratifying and is much appreciated. The Disease at a Glance features have been widely praised by instructors and students, so I, along with art editor Kelly Murphy, developed six new Disease in Depth spreads that use compelling art and photos to provide a detailed overview of a specific disease. Each spread features an Investigate It! question with a QR code directing students to a website, encouraging further, independent research. Another goal for this edition was to provide additional instruction on important concepts and processes. To that end, I developed and narrated the Video Tutors, accessible via QR codes in the textbook and in MasteringMicrobiology®. The result is, once again, a collaborative effort of educators, students, editors, and top scientific illustrators: a textbook that, I hope, continues to improve upon conventional explanations and illustrations in substantive and effective ways.

In this new edition:

- **NEW Disease in Depth** spreads feature important and representative diseases for each body system, extending the visual impact of the art program as well as the highly praised Disease at a Glance features. Each of these six visual spreads contains info-graphics, provides in-depth coverage of the selected disease, and includes a QR code and Investigate It! question that directs students to a major health website, prompting further exploration and critical thinking. New MasteringMicrobiology assignable Disease in Depth coaching activities encourage students to apply and test their understanding of key concepts.

- **NEW Video Tutors** developed and narrated by the author walk students through key concepts in microbiology, bringing the textbook art to life and helping students visualize and understand tough topics and important processes. These 18 video tutorials are accessible via QR codes in the textbook and are accompanied by multiple-choice questions, assignable in MasteringMicrobiology®.
- **NEW Tell Me Why** critical thinking questions end every main section within each chapter. These questions strengthen the pedagogy and organization of each chapter and *consistently* provide stop-and-think opportunities for students as they read.
- **NEW Expanded coverage of helminths** is provided in new highlight features, and an **emphasis on virulence factors** is included in Disease at a Glance and Disease in Depth features.
- **NEW Numbered Learning Outcomes** in the textbook are used to tag Test Bank questions and all Mastering assets. In addition to being tagged to Learning Outcomes, all Mastering assessments are tagged to the Global Science Learning Outcomes and Bloom's Taxonomy. The complete Mastering Test Bank is also tagged to ASMCUE recommended outcomes.
- **NEW Visualize It!** features appear at the end of each chapter. These short-answer or fill-in-the-blank questions are built around illustrations or photos. These are also assignable as art labeling activities in MasteringMicrobiology.
- **The immunology chapters (Chapters 15–18),** which have been and continue to be reviewed in-depth by immunology specialists, reflect the most current understanding of this rapidly evolving field.
- **Over 50 NEW micrographs and photos** enhance student understanding of the text and boxed features.
- **NEW MasteringMicrobiology** includes NEW Disease in Depth and Disease at a Glance coaching activities, NEW Video Tutors with assessments, NEW MicroCareers and Clinical Case Study coaching activities, NEW Visualize It! art labeling activities, and Microbiology Lab Technique videos with assessment and MicroLab Tutor coaching activities. MicroLab Tutors use lab technique videos, 3D molecular animations, and stepped-out tutorials to actively engage students in making the connection between microbiology lecture, lab, and the real world. Disease at a Glance coaching activities ask students to categorize and sort diseases by different concepts, that is, by mode of transmission, signs and symptoms, etc. Additionally, MasteringMicrobiology and the Study Area include NEW MicroLab Practical quizzes, allowing more opportunities to analyze and interpret important lab tests, techniques, and results.

The following section provides a detailed outline of this edition's chapter-by-chapter revisions.

Chapter-by-Chapter Revisions

Every chapter in this edition has been thoroughly revised, and data in the text, tables, and figures have been updated. All Learning Outcomes have been numbered and are tagged to Test Bank questions and Mastering assets. Critical Thinking questions, formerly placed throughout each chapter, are now included in the end-of-chapter content.

The main changes for each chapter are summarized below.

THROUGHOUT THE DISEASE CHAPTERS (19–24)

- Updated disease diagnoses, treatments, and incidence and prevalence data
- Updated immunization recommendations and suggested treatments for all diseases
- Expanded coverage of virulence factors

CHAPTER 1 A BRIEF HISTORY OF MICROBIOLOGY

- Three new Tell Me Why questions
- Four photos replaced for improved pedagogy (Figures 1.5a and b, 1.7b, 1.17)
- One figure revised for improved pedagogy (Figure 1.13)
- Update to CDC-preferred term *healthcare associated infection (HAI)* (formerly *nosocomial infection*)
- New introductory coverage of normal microbiota and agar
- Clarified the use of a control in Pasteur's experiment to disprove spontaneous generation
- Clarified industrial use of microbes in making yogurt and in pest control
- Three new critical thinking questions in the Emerging Disease Case Study: Variant Creutzfeldt-Jakob Disease
- New Clinical Case Study: Can Spicy Food Cause Ulcers?
- New end-of-chapter Short Answer question on healthcare associated (nosocomial) infections
- New Visualize It! question on Pasteur's experiment to disprove spontaneous generation
- New Video Tutor: The Scientific Method

CHAPTER 2 THE CHEMISTRY OF MICROBIOLOGY

- Five new Tell Me Why questions
- Twelve figures revised for improved clarity and pedagogy (Figures 2.2, 2.3, 2.5, 2.7, 2.10–2.12, 2.15, 2.19, 2.20, 2.24, 2.26)
- New figure legend question (Figure 2.3)
- Expanded coverage of term *nucleoside* (nucleoside analogs treat a number of diseases)
- New Visualize It! question on the structure of amino acids
- New Video Tutor: The Structure of Nucleotides

CHAPTER 3 CELL STRUCTURE AND FUNCTION

- Twelve new Tell Me Why questions
- Four new/upgraded photos (Figures 3.7a and b, 3.8, 3.11)
- Five figures revised for improved clarity and pedagogy (Figures 3.9, 3.14, 3.15, 3.20, 3.24)
- Enhanced discussion of bacterial cytoskeletons and of bacterial and archaeal flagella
- Enhanced discussion of the roles of glycocalyces in biofilms
- New Visualize It! question on bacterial flagellar arrangements
- New Video Tutor: Bacterial Cell Walls

CHAPTER 4 MICROSCOPY, STAINING, AND CLASSIFICATION

- Four new Tell Me Why questions
- Four figures revised for improved clarity and pedagogy (Figures 4.2, 4.5, 4.6, 4.17)
- Three new critical thinking questions and one new photo in the Emerging Disease Case Study: Necrotizing Fasciitis
- New Visualize It! question on the light microscope
- New Video Tutor: The Light Microscope

CHAPTER 5 MICROBIAL METABOLISM

- Six new Tell Me Why questions
- Seven figures revised for improved clarity and pedagogy (Figures 5.3, 5.6, 5.10, 5.14, 5.16, 5.17, 5.26)
- Two new figure legend questions (Figures 5.4, 5.12)
- Expanded coverage of vitamins as enzymatic cofactors
- Updated text and figure legends that more clearly explain energy transfer in glycolysis, the Krebs cycle, and electron transport
- Updated text clarifying that glycolysis, the pentose phosphate pathway, and the Krebs cycle supply numerous precursor metabolites for anabolism
- Expanded discussion of bacterial quorum sensing and biofilms
- New end-of-chapter Fill in the Blanks question on anaerobic respiration
- New Visualize It! question on locating glycolysis, the Krebs cycle, and electron transport in eukaryotes
- New Video Tutor: Electron Transport Chains

CHAPTER 6 MICROBIAL NUTRITION AND GROWTH

- Three new Tell Me Why questions
- Two figures revised for improved clarity and pedagogy (Figures 6.1, 6.20)
- Significantly expanded coverage of biofilms and quorum sensing, including a new figure (Figure 6.7)
- Updated Beneficial Microbes: A Nuclear Waste–Eating Microbe?
- New Clinical Case Study about dental caries
- New Clinical Case Study about MRSA infection in a high school
- New Visualize It! question on identifying beta hemolysis
- New Video Tutor: Bacterial Growth Media

CHAPTER 7 MICROBIAL GENETICS

- Four new Tell Me Why questions
- Eleven figures upgraded for greater clarity, accuracy, ease of reading, and better pedagogy (Figures 7.1, 7.4, 7.5, 7.6, 7.9, 7.10, 7.21, 7.24, 7.30, 7.34, 7.37)
- Expanded coverage of the difference between nucleoside and nucleotide (many antimicrobial drugs are analogs of the former, not the latter)
- Clarified section on operons, introduction of the term *polycistronic*, new discussion of quorum-sensing as a trigger for inducible and repressible operons

- Section on regulatory RNA molecules updated for clarity and for inclusion of newly discovered information
- Three new critical thinking questions in Emerging Disease Case Study: *Vibrio vulnificus* Infection
- New Visualize It! question on DNA structure
- New Video Tutor: Initiation of Translation

CHAPTER 8 RECOMBINANT DNA TECHNOLOGY

- Five new Tell Me Why questions
- One new photo (chapter opener)
- Two figures revised for improved pedagogy (Figures 8.2, 8.9)
- New section discussing use of recombinant DNA techniques to address environmental problems, such as the reemergence of dengue fever
- Expanded coverage of the debate concerning genetic modification of agricultural products
- New Highlight: How Do You "Fix" a Mosquito?
- New Highlight: Vaccines on the Menu
- New Visualize It! question on DNA "fingerprinting"
- New Video Tutor: Action of Restriction Enzymes

CHAPTER 9 CONTROLLING MICROBIAL GROWTH IN THE ENVIRONMENT

- Four new Tell Me Why questions
- New photo (Figure 9.9)
- Three figures revised for improved clarity and pedagogy (Figures 9.1, 9.4, 9.13)
- Reorganization of the topics "Methods for Evaluating Disinfectants and Antiseptics" and "Biosafety Levels" for better flow and pedagogy
- New Highlight: Microbes in Sushi?
- Three new critical thinking questions in Emerging Disease Case Study: *Acanthamoeba* Keratitis
- New end-of-chapter critical thinking question on salmonellosis pandemic from smoked salmon
- New Visualize It! question on metal ions as a traditional water disinfectant in India
- New Video Tutor: Principles of Autoclaving

CHAPTER 10 CONTROLLING MICROBIAL GROWTH IN THE BODY: ANTIMICROBIAL DRUGS

- Four new Tell Me Why questions
- One new photo (Figure 10.10)
- Eight figures revised for currency, improved clarity, and pedagogy (Figures 10.2, 10.3, 10.4, 10.6, 10.8, 10.10, 10.15; Emerging Disease Case Study: Community-Associated MRSA map)
- Expanded coverage of the terms *therapeutic index* and *therapeutic window* as applied to antimicrobials
- New coverage on transfer of resistance genes between and among bacteria and on research to discover novel antimicrobials; updated discussion of the efficacy of probiotics
- Updated tables of antimicrobials to include all new antimicrobials mentioned in disease chapters, including antibacterial carbapenems; new antiprotozoan drugs (lumefantrine, nitazoxanide, paromoycin, piperaquine, and tinidazole); the newly approved anti-HIV-1 drug enfuvirtide; the antifungal drug ciclopirox; and antiviral protease inhibitors (boceprevir, darunavir, and telaprevir)
- New end-of-chapter critical thinking question on development of antimicrobial resistance
- Three new critical thinking questions in Emerging Disease Case Study: Community-Associated MRSA
- Nine new Learning Outcomes
- New Visualize It! question on Etest interpretation
- New Video Tutor: Action of Some Drugs that Inhibit Prokaryotic Protein Synthesis

CHAPTER 11 CHARACTERIZING AND CLASSIFYING PROKARYOTES

- Four new Tell Me Why questions
- Fourteen new photos (Figures 11.1, 11.2, 11.7, 11.17, 11.22, 11.23b, 11.24, 11.25b)
- Eight revised figures for improved clarity and pedagogy (Figures 11.1, 11.2, 11.4, 11.5, 11.6, 11.10, 11.21, 11.25)
- Clarified and expanded coverage of "snapping division," which is a distinctive characteristic of corynebacteria, including *C. diphtheriae*
- Updated taxonomy to correspond more completely with current *Bergey's Manual*
- New Beneficial Microbes: Botulism and Botox
- Enhanced discussion of nitrogen fixation, nitrification, and action of *Agrobacterium*
- New Highlight: Your Teeth Might Make You Fat
- Three new critical thinking questions in Emerging Disease Case Study: Pertussis
- Six new Learning Outcomes
- New Visualize It! on endospore identification
- New Video Tutor: Arrangements of Prokaryotic Cells

CHAPTER 12 CHARACTERIZING AND CLASSIFYING EUKARYOTES

- Six new Tell Me Why questions
- Eight new photos (Figures 12.11, 12.13, 12.15a-b, 12.23b, 12.29, 12.30, 12.33e)
- Five revised figures for improved clarity and pedagogy (Figures 12.1, 12.8, 12.11, 12.22, 12.33e)
- Updated algal, fungal, protozoan, water mold, and slime mold taxonomy
- Simplification of the vocabulary in the coverage of the morphology and reproductive strategies of fungi
- New Visualize It! question concerning fungal life cycles
- New Video Tutor: Principles of Sexual Reproduction in Fungi

CHAPTER 13 CHARACTERIZING AND CLASSIFYING VIRUSES, VIROIDS, AND PRIONS

- Four new Tell Me Why questions
- Five new photos (Figures 13.1b, 13.5c, 13.21, 13.23; Beneficial Microbes: Prescription Bacteriophages? photo)
- Four figures revised for improved pedagogy and currency (Figures 13.8, 13.11, 13.13, 13.22)
- Updated viral nomenclature to correspond to changes approved by the International Committee on Taxonomy of Viruses (ICTV)
- New coverage of discovery of *Megavirus*—the largest virus
- Three new critical thinking questions in updated Emerging Disease Case Study: Chikungunya
- New Visualize It! question on recognizing viral shapes in transmission electron micrographs
- New Video Tutor: The Lytic Cycle of Viral Replication

CHAPTER 14 INFECTION, INFECTIOUS DISEASES, AND EPIDEMIOLOGY

- Eight new Tell Me Why questions
- Three new photos (Figures 14.10, 14.6, 14.13)
- Seven figures updated for currency, improved clarity, and pedagogy (Figures 14.8, 14.9, 14.10, 14.14, 14.15, 14.19, 14.20)
- Updated epidemiology charts, tables, and graphs

- Updated list of nationally notifiable infectious diseases
- New discussion of hemolytic uremic syndrome (caused by *E. coli*), provided as an example of an epidemic with reference to an emerging disease (replaces prior discussion of *Hantavirus* pulmonary syndrome)
- New discussion of human West Nile virus infection added to explain the ways epidemiologists report their findings (replaces prior discussion of shigellosis)
- New figure legend questions (Figures 14.15, 14.18)
- Three new critical thinking questions in Emerging Disease Case Study: *Hantavirus* Pulmonary Syndrome
- New Visualize It! question on recognizing viral shapes in transmission electron micrographs
- New Video Tutor: Some Virulence Factors

CHAPTER 15 INNATE IMMUNITY

- Two new Tell Me Why questions
- Six figures revised for improved clarity and pedagogy, including a new rendition to reflect more accurately the sequence of complement cascade and action of complement subunits (Figures 15.6, 15.9, 15.11–14)
- Expanded coverage of the action of antimicrobial peptides (defensins)
- Expanded coverage of NOD receptor proteins and their role in protecting against hepatitis C, AIDS, and mononucleosis
- New Visualize It! question on identification of white blood cells
- New Video Tutor: Inflammation

CHAPTER 16 ADAPTIVE IMMUNITY

- Three new Tell Me Why questions
- Two new photos (Figures 16.1, 16.6)
- Twelve figures revised for improved clarity, pedagogy, and currency (Figures 16.2–16.5, 16.8–16.13, 16.18; Emerging Disease Case Study: Microsporidiosis map)
- Text reorganized to present discussion of T cells, major histocompatibility, antigen processing and presentation, and T cell clonal deletion before the discussion of B cells and B cell clonal deletion
- Three new critical thinking questions in Emerging Disease Case Study: Microsporidiosis
- Revised Learning Outcomes
- New Visualize It! question on major histocompatibility complex proteins
- New Video Tutor: Clonal Deletion

CHAPTER 17 IMMUNIZATION AND IMMUNE TESTING

- Two new Tell Me Why questions
- New photo (Figure 17.10)
- Five figures revised for improved clarity and pedagogy (Figures 17.1–17.3, 17.8, 17.14)
- New CDC 2013 vaccination schedule for children, adolescents, and adults
- Updated table of vaccine-preventable diseases in the United States
- New coverage of quantifying immunoassays—turbidimetry and nephelometry
- New Visualize It! question on interpreting an immunoblot
- New Video Tutor: ELISA

CHAPTER 18 AIDS AND OTHER IMMUNE DISORDERS

- Three new Tell Me Why questions
- New photo (Figure 18.11)
- Two new figures (Figures 18.16, 18.17)
- Three revised figures for improved clarity and pedagogy (Figures 18.8, 18.20, 18.21)
- Updated discussion of AIDS prevalence, transmission, prevention, and treatment
- Updated discussion of HIV attachment, entry, and replication
- New Visualize It! question on recognizing type I, III, and IV hypersensitivities
- New Video Tutor: Hemolytic Disease of the Newborn

CHAPTER 19 MICROBIAL DISEASES OF THE SKIN AND WOUNDS

- Five new Tell Me Why questions
- Ten new photos (Figures 19.7, 19.13, 19.15, 19.17; Disease in Depth and Disease at a Glance figures for *Pseudomonas*, Rocky Mountain spotted fever [RMSF], smallpox, herpes, shingles)
- Three figures revised for improved accuracy, pedagogy, and currency (Figure 19.1; Emerging Disease Case Study: Buruli Ulcer map; Emerging Disease Case Study: Monkeypox map)
- Coverage of spotted fever rickettsioses revised to clarify that Rocky Mountain spotted fever (RMSF) is only one type and to explain that one reason rickettsias are obligate intracellular parasites is their requirement for amino acids and Krebs cycle intermediates
- Updated coverage of chickenpox and shingle vaccine
- Updated treatment regimens for staphylococcal scalded skin syndrome, impetigo, erysipelas, cat scratch disease, cutaneous anthrax, gas gangrene, herpes skin infections, chickenpox, shingles, measles, erythema infectiosum, hand-foot-and-mouth disease, pityriasis versicolor, cutaneous mycoses, chromoblastomycosis, sporotrichosis, and leishmaniasis
- Expanded coverage of methicillin-resistant and vancomycin-resistant *Staphylococcus aureus* (MRSA, VRSA)
- Expanded and updated coverage of action of anthrax toxins
- Three new critical thinking questions in Emerging Disease Case Study: Buruli Ulcer
- Three new critical thinking questions in Emerging Disease Case Study: Monkeypox
- One new end-of-chapter multiple choice question
- Seven new Learning Outcomes
- New Visualize It! question on identification of skin infections
- New Disease at a Glance: *Pseudomonas* Infection
- New Disease in Depth: Necrotizing Fasciitis

CHAPTER 20 MICROBIAL DISEASES OF THE NERVOUS SYSTEM AND EYES

- Six new Tell Me Why questions
- Sixteen new photos (Figures 20.3, 20. 4, 20.14, Highlight: Nipah virus; Clinical Case Studies: Ptosis burnt fingers and N. meningitidis; Disease at a Glance: West Nile Encephalitis; Disease in Depth feature)
- Eight figures revised for currency and improved pedagogy (Figures 20.1, 20.2, 20.10, 20.14, 20.15, 20.16; Emerging Disease Case Study: Melioidosis map, Emerging Disease Case Study: Tick-Borne Encephalitis map)
- Expanded coverage of virulence factors and pathogenesis of diseases, particularly botulism, West Nile virus encephalitis, African sleeping sickness
- Updated treatment regimens for bacterial meningitis, leprosy, foodborne botulism, cryptococcal meningitis, primary amebic meningoencephalopathy, variant Creutzfeldt-Jakob disease, and chlamydial eye infections.
- Three new critical thinking questions in Emerging Disease Case Study: Melioidosis
- Three new critical thinking questions in Emerging Disease Case Study: Tick-Borne Encephalitis
- New Highlight: Nipah Virus: From Pigs to Humans
- New Visualize It! question on lumbar puncture
- New Disease at a Glance: Polio
- New Disease in Depth: Listeriosis

CHAPTER 21 CARDIOVASCULAR AND SYSTEMIC DISEASES

- Four new Tell Me Why questions
- Eighteen new photos (Figures 21.5, 21.13; Beneficial Microbes: Wolbachia; Clinical Case Study: A Tired Freshman, and Man and Cat; Highlight: Malaria; Emerging Disease Case Study: Schistosomiasis; Disease at a Glance: Toxoplasmosis; Disease in Depth feature)
- Thirteen figures revised for currency and improved pedagogy (Figures 21.1, 21.6, 21.9, 21.10, 21.12, 21.16, 21.17, 21.20, 21.21, 21.22; Disease at a Glance: Yellow Fever; Emerging Disease Case Study: Schistosomiasis map; Emerging Disease Case Study: Snail Fever in China map)
- New Clinical Case Study: Nightmare on the Island
- Three new critical thinking questions in Emerging Disease Case Study: Snail Fever in China
- Updated treatment regimens for tularemia, Lyme disease, ehrlichiosis, anaplasmosis, cytomegalovirus disease, malaria, toxoplasmosis, and schistosomiasis
- Two new Learning Outcomes
- New Visualize It! question on Lyme disease
- New Disease at a Glance: Toxoplasmosis
- New Disease in Depth: Malaria

CHAPTER 22 MICROBIAL DISEASES OF THE RESPIRATORY SYSTEM

- Three new Tell Me Why questions
- Twenty-one new photos (chapter opener photo; Figures 22.2, 22.3, 22.4, 22.9, 22.13, 22.17; Disease at a Glance features: Bacterial Pneumonias, Coronavirus Respiratory Syndromes, Respiratory Syncytial Virus Infection, and Histoplasmosis; Clinical Case Study: The Coughing Cousin; Disease in Depth feature)
- Five figures revised for currency and improved pedagogy (Figures 22.1, 22.10, 22.11; Emerging Disease Case Study: Pulmonary Blastomycosis map; Emerging Disease Case Study: H1N1 Influenza map)
- New table comparing and contrasting manifestations of some common respiratory diseases (Table 22.1)
- New discussion of Middle East respiratory syndrome (MERS)
- Expanded discussion of diphtheria, tetanus, pertussis vaccine schedule, and the vaccines' nomenclature
- Introduced new preferred term *rhinosinusitis* to replace *sinusitis*
- Updated treatment regimens for bacterial pneumonia, pneumonic plague, ornithosis, Legionnaires' disease, drug-susceptible tuberculosis (TB), multi-drug-resistant TB (MDR-TB), whooping cough, inhalational anthrax, blastomycosis, and histoplasmosis
- Expanded coverage of multi-drug-resistant tuberculosis (MDR-TB) and extensively drug-resistant TB (XDR-TB)
- Three new critical thinking questions in Emerging Disease Case Study: H1N1 Influenza
- Three new critical thinking questions in Emerging Disease Case Study: Pulmonary Blastomycosis
- New Visualize It! question on bacteria
- New Disease at a Glance: Respiratory Syncytial Virus Infection
- New Disease in Depth: Tuberculosis

CHAPTER 23 MICROBIAL DISEASES OF THE DIGESTIVE SYSTEM

- Four new Tell Me Why questions
- Fifteen new photos (Figures 23.6. 23.11, 23.17b; Disease at a Glance features: Dental Caries, Cholera, and Amebiasis; Disease in Depth feature)
- Five figures revised for currency and improved pedagogy (Figures 23.5, 23.6, 23.14, 23.15, 23.18)
- Updated treatment regimens for peptic ulcers, cholera, shigellosis, traveler's diarrhea, *C. diff* diarrhea/colitis, typhoid fever, oral herpes, hepatitis C, and cryptosporidiosis
- Expanded coverage of Shiga-like toxins, probiotics, oral herpes, hepatitis viruses C and E, the newly approved xTAG Gastrointestinal Pathogen Panel (xTAG GPP) as a way to diagnose causes of gastroenteritis, *Clostridium difficile* diarrhea, and pseudomembranous colitis
- New coverage of the connection between esophageal cancer and the use of antibiotics to treat *Helicobacter* infection
- New coverage of anisakiasis
- New coverage of the reintroduction of the cholera pandemic into North America (Haiti, 2010; Dominican Republic, 2011; Cuba, 2013)
- Three new critical thinking questions in Emerging Disease Case Study: *Norovirus* Gastroenteritis
- One new Learning Outcome
- New Visualize It! question on hepatitis B virus, Dane particles, filamentous particles, and spherical particles
- New Disease at a Glance: Dental Caries
- New Disease in Depth: Giardiasis

CHAPTER 24 MICROBIAL DISEASES OF THE URINARY AND REPRODUCTIVE SYSTEMS

- Seven new Tell Me Why questions
- Twelve new photos (Figures 24.4, 24.12, Beneficial Microbes: Pharmacists of the Future?; Disease at a Glance: Gonorrhea and Genital Warts; Disease in Depth)
- Eight new figures (Figures 23.4, 24.6a, 24.6c, 24.7b, 24.8, 24.13; Disease at a Glance features: Candidiasis, Gonorrhea)
- Five figures revised for currency and improved pedagogy (Figures: 24.3, 24.5, 24.7a, 24.9, 24.11)
- Updated treatment regimens for urinary tract infections, leptospirosis, staphylococcal toxic shock syndrome, lymphogranuloma venereum, gonorrhea, neonatal chlamydial conjunctivitis, and trichomoniasis
- Two new Learning Outcomes
- New Visualize It! question on pathogens of the urinary and reproductive systems
- New Disease at a Glance: Trichomoniasis
- New Disease in Depth: Bacterial Urinary Tract Infections

CHAPTER 25 APPLIED AND ENVIRONMENTAL MICROBIOLOGY

- Four new Tell Me Why questions
- Five new photos (Figures 25.3, 25.6, 25.7, 25.14; Emerging Disease Case Study: Attack in the Lake)
- New figure legend question concerning food sterilization
- Clarification of the terms *unripened* and *ripened* in regard to cheeses and expanded coverage of the processes of cheese-making
- New coverage of biomining—the use of microbes to extract insoluble forms of metals from ore
- New coverage on the presence of significant nitrogen fixation by deep-sea archaea associated in microbial communities with bacteria
- New Emerging Disease Case Study: Attack in the Lake
- New Beneficial Microbes: Oil-Eating Microbes to the Rescue in the Gulf
- New Visualize It! question on nitrogen cycling

Reviewers for the Fourth Edition

I wish to thank the hundreds of instructors and students who participated in reviews, class tests, and focus groups for earlier editions of the textbook. Your comments have informed this book from beginning to end, and I am deeply grateful. For the fourth edition, I extend my deepest appreciation to the following reviewers.

Book Reviewers

Warner B. Bair III
Lone Star College—CyFair

Carrie Burdinski
Delta College

Bradley W. Christian
McLennan Community College

Pamela J. Coker
Pima Community College

Francisco Cruz
Georgia State University

Michael J. Dul
Lakeland Community College and *Fortis College*

Clifton Franklund
Ferris State University

Nicholas Hackett
Moraine Valley Community College

Robert Iwan
Inver Hills Community College

Timothy Johnson
University of Minnesota

James Masuoka
Midwestern State University

Laura Mery
San Antonio College

Jennifer A. Metzler
Ball State University

Ron C. Michaelis
Rutgers University

Karen Persky
College of DuPage

Michael Pressler
Delta College

Nancy Risner
Ivy Tech Community College—Muncie

Ben Rowley
University of Central Arkansas

Debra Scheiwe
Tarrant County College—Northeast

Audra Swarthout
Delta College

Patricia G. Wilber
Central New Mexico Community College

Elizabeth Yelverton
Pensacola State College

Kathy A. Zarilla
Durham Technical Community College

Video Tutor Reviewers

Cheryl Boice
Florida Gateway College

Carroll Weaver Bottoms
Collin College

Teresa G. Fischer
Indian River State College

Leoned Gines
Shoreline Community College

Nicholas Hackett
Moraine Valley Community College

Jennifer Hatchel
College of Coastal Georgia

James B. Herrick
James Madison University

Robert Iwan
Inver Hills Community College

Mary Evelyn B. Kelley
Wayne State University

Denice D. King
Cleveland State Community College

Kevin Mitchell
Northern Essex Community College

Stacy Pfluger
Angelina College

Nancy Risner
Ivy Tech Community College—Muncie

Jennifer Swartz
Pikes Peak Community College

Acknowledgments

As was the case with all the previous editions, this book has truly been a team effort. I am deeply grateful to Kelsey Churchman of Pearson Science and to the team she gathered to produce the fourth edition. Kelsey, dedicated project editor Nicole McFadden, Barbara Yien, project editor of the first two editions, and Robin Pille, project editor of the third edition, helped develop the vision for this fourth edition, coming up with ideas for making it more effective and compelling. As project editor, Nicole also had the unenviable task of coordinating everything and keeping me on track—thank you, Nicole, for being understanding, patient, and lenient with the "dead" in deadline. Thank you, Barbara, for years of support and for introducing me to chocolate truffles. I am excited about your growing adventure! I am grateful to Frank Ruggirello for his unflagging encouragement and support of my work and this book. I am also indebted to Daryl Fox, whose early support for this book never wavered.

Sally Peyrefitte—the eagle-eyed—edited the manuscript thoroughly and meticulously, suggesting important changes for clarity, accuracy, and consistency. Kelly Murphy did an incredibly superb job as art development editor, helping to conceptualize new illustrations and suggesting ways to improve the art overall—thank you, Kelly. My friend Ken Probst is responsible for originally creating this book's amazingly beautiful biological illustrations. My thanks to Precision Graphics for rendering the art in this edition. Nancy Tabor and Lori Bradshaw expertly guided the project through production. Maureen "Mo" Spuhler continued her absolutely incredible job researching photos. I am in your debt, Mo. Rich Robison and Brent Selinger supplied many of the text's wonderful and unique micrographs. Tamara Newman created the beautiful interior design and the stunning cover.

Thanks to Nichol Dolby and Sam Schwarzlose of Amarillo College; Suzanne Long of Monroe Community College; Mindy Miller-Kittrell of University of Tennessee, Knoxville; Jason Andrus of Meredith College; Tiffany Glaven of University of California, Davis; Kathryn Sutton of Clarke College; and Judy Meier Penn of Shoreline Community College for their work on the media and print supplements for this edition. Special thanks are due to Ashley Williams and Denise Wright for managing the supplements, to Shannon Kong in production for her work on the Instructor's Resource DVD, and to Annie Wang for her management of the extraordinary array of media resources for students and instructors, especially MasteringMicrobiology®. Thanks also to Nan Kemp, Corey Webb, Maddie Boston, and Jordan Roeder, RN for their administrative, editorial, and research assistance. Chris Feldman proofread and checked pages—without her help the book would be less useful. I am always grateful to Neena Bali in Marketing and the amazing Pearson sales representatives for continuing to do a terrific job of keeping in touch with the professors and students who provided so many wonderful suggestions for this textbook. You sales representatives inspire and humble me, and your role on the team deserves more praise than I can express here.

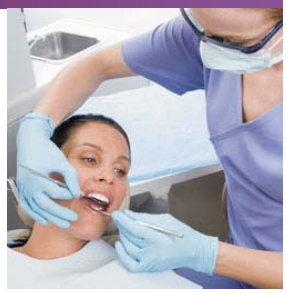
I am especially grateful to Phil Mixter of Washington State University, Mary Jane Niles of the University of San Francisco, Bronwen Steele of Estrella Mountain Community College, Jan Miller of American River College, and Jane Reece for their expertise and advice.

I am also indebted to Sam Schwarzlose for his excellent work on the Video Tutor assessments, to Terry Austin for lending his technical expertise to the project, and to all Video Tutor reviewers for their contribution to this great pedagogical tool.

On the home front, "Thank you," Jennie and Nick Knapp, Elizabeth Bauman, Larry Latham, Josh Wood, and Mike Isley. You keep me even-keeled. My wife Michelle deserves more recognition than I can possibly express: "Many have done nobly, but you excel them all. Thank you."

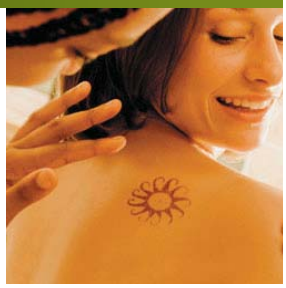
Robert W. Bauman
Amarillo, Texas

Table of Contents



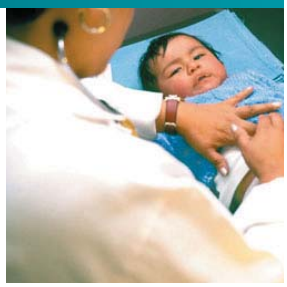
7

Microbial Genetics 196



8

Recombinant DNA Technology 240

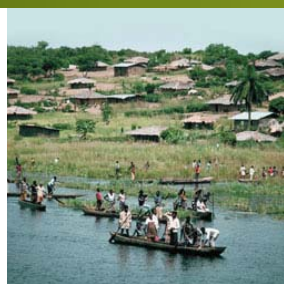


9

Controlling Microbial Growth in the Environment 262

13

Characterizing and Classifying Viruses, Viroids, and Prions 386



14

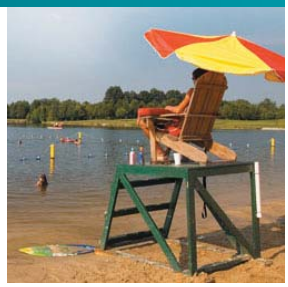
Infection, Infectious Diseases, and Epidemiology 414

15

Innate Immunity 448

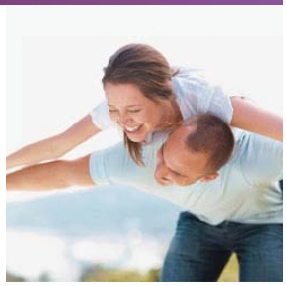
23

Microbial Diseases of the Digestive System 715



24

Microbial Diseases of the Urinary and Reproductive Systems 753



25

Applied and Environmental Microbiology 783

Feature Boxes

BENEFICIAL MICROBES

HIGHLIGHT

EMERGING DISEASE CASE STUDY

CLINICAL CASE STUDY

DISEASE AT A GLANCE

DISEASE IN DEPTHS

1 A Brief History of Microbiology

MICRO IN THE CLINIC

A Simple Case of Traveler's Diarrhea?

Martin is a nurse in Chicago. Every summer, he spends a few weeks in Africa volunteering in a rural village in Zambia. The village has no sanitation system and gets its water from a nearby shallow well. Over time, Martin has gained the villagers' trust and demonstrated handwashing technique, safer food preparation, and other ways to prevent infectious disease. Water purification is especially a challenge: boiling water requires fuel that isn't always available, and chemicals that make water safer to drink are often in short supply.

During the last week of Martin's most recent Africa trip, torrential rains hit the country, causing flash floods and extensive damage to the village. Despite the conditions, Martin manages to return to Chicago on schedule. A day later, he begins experiencing diarrhea. At first, he brushes it off as "traveler's diarrhea," which can be caused by a change in diet and usually goes away quickly. However, over the following days, Martin's symptoms worsen. The diarrhea is much more severe than anything Martin has experienced before; it is milky, with flecks of mucus, and frightening-looking. Martin also develops nausea, vomiting, and muscle cramps. He drinks massive amounts of water and tries over-the-counter diarrhea medicine, but nothing he does relieves the symptoms.

Is Martin suffering from a simple case of "traveler's diarrhea"? Or is something more serious going on? Turn to the end of the chapter (p. 21) to find out.

MM **Explore More:** Test your readiness and apply your knowledge with dynamic learning tools at MasteringMicrobiology.

Science is the study of nature that proceeds by posing questions about observations. Why are there seasons? What is the function of the nodules at the base of this plant? Why does this bread taste sour? What does plaque from between teeth look like when magnified? Why are so many crows dying this winter? What causes new diseases?

Many early written records show that people have always asked questions like these. For example, the Greek physician Hippocrates (ca. 460–ca. 377 B.C.) wondered whether there is a link between environment and disease, and the Greek historian Thucydides (ca. 460–ca. 404 B.C.) questioned why he and other survivors of the plague could have intimate contact with victims and not fall ill again. For many centuries, the answers to these and other fundamental questions about the nature of life remained largely unanswered. But about 350 years ago, the invention of the microscope began to provide some clues.

In this chapter we'll see how one man's determination to answer a fundamental question about the nature of life—What does life really look like?—led to the birth of a new science called *microbiology*. We'll then see how the search for answers to other questions, such as those concerning spontaneous generation, the reason fermentation occurs, and the cause of disease, prompted advances in this new science. Finally, we'll look briefly at some of the key questions microbiologists are asking today.

The Early Years of Microbiology

The early years of microbiology brought the first observations of microbial life and the initial efforts to organize them into logical classifications.

What Does Life Really Look Like?

LEARNING **OUTCOMES**

1.1 Describe the world-changing scientific contributions of Leeuwenhoek.

1.2 Define microbes in the words of Leeuwenhoek and as we know them today.

A few people have changed the world of science forever. We've all heard of Galileo, Newton, and Einstein, but the list also includes Antoni van Leeuwenhoek (lā´vĕn-huk; 1632–1723), a Dutch tailor, merchant, and lens grinder, and the man who first discovered the bacterial world **(FIGURE 1.1)**.

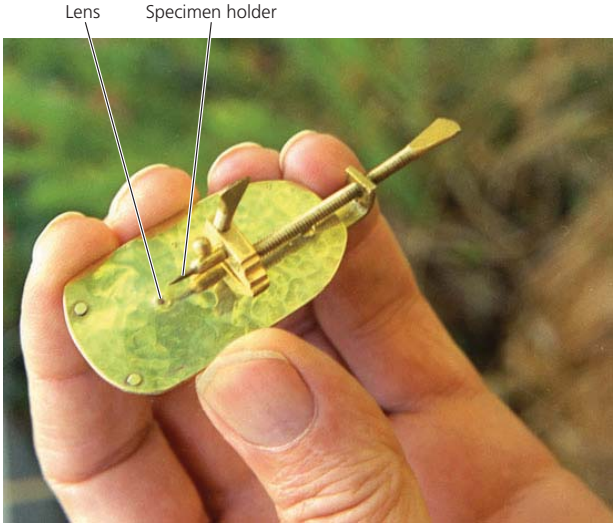
Leeuwenhoek was born in Delft, the Netherlands, and lived most of his 90 years in the city of his birth. What set Leeuwenhoek apart from most other men of his generation was an insatiable curiosity coupled with an almost stubborn desire to do everything for himself. His journey to fame began simply enough, when as a cloth merchant he needed to examine the quality of cloth. Rather than merely buying one of the magnifying lenses already available, he learned to make glass lenses of his own **(FIGURE 1.2)**. Soon he began asking, "What does it really look like?" of everything in his world: the stinger of a bee,

▲ **FIGURE 1.1 Antoni van Leeuwenhoek.** Leeuwenhoek reported the existence of protozoa in 1674 and of bacteria in 1676. *Why did Leeuwenhoek discover protozoa before bacteria?*

Figure 1.1 *Protozoa are generally larger than bacteria.*

the brain of a fly, the leg of a louse, a drop of blood, flakes of his own skin. To find answers, he spent hours examining, reexamining, and recording every detail of each object he observed.

Making and looking through his simple microscopes, most really no more than magnifying glasses, became the overwhelming passion of his life. His enthusiasm and dedication are evident from the fact that he sometimes personally extracted the



▲ **FIGURE 1.2 Reproduction of Leeuwenhoek's microscope.** This simple device is little more than a magnifying glass with screws for manipulating the specimen, yet with it, Leeuwenhoek changed the way we see our world. The lens, which is convex on both sides, is about the size of a pinhead. The object to be viewed was mounted either directly on the specimen holder or inside a small glass tube, which was then mounted on the specimen holder.

metal for his microscope from ore. Further, he often made a new microscope for each specimen, which remained mounted so that he could view it again and again. Then one day, he turned a lens onto a drop of water. We don't know what he expected to see, but certainly he saw more than he had anticipated. As he reported to the Royal Society of London[1] in 1674, he was surprised and delighted by

> some green streaks, spirally wound serpent-wise, and orderly arranged. . . . Among these there were, besides, very many little animalcules, some were round, 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. . . . 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.

Leeuwenhoek had discovered a previously unknown microbial world, which today we know to be populated with tiny animals, fungi, algae, and single-celled protozoa **(FIGURE 1.3)**. In a later report to the Royal Society, he noted that

> the number of these animals in the plaque of a man's teeth, are so many that I believe they exceed the number of men in a kingdom. . . . I found too many living animals therein, that I guess there might have been in a quantity of matter no bigger than the 1/100 part of a [grain of] sand.

From the figure accompanying his report and the precise description of the size of these organisms from between his teeth, we know that Leeuwenhoek was reporting the existence of bacteria. By the end of the 19th century, Leeuwenhoek's "beasties," as he sometimes dubbed them, were called **microorganisms**, and today we also know them as **microbes**. Both terms include all organisms that are too small to be seen without a microscope.

Because of the quality of his microscopes, his profound observational skills, his detailed reports over a 50-year period, and his report of the discovery of many types of microorganisms, Antoni van Leeuwenhoek was elected to the Royal Society in 1680. He and Isaac Newton were the most famous scientists of their time.

How Can Microbes Be Classified?

LEARNING **OUTCOMES**

1.3 List six groups of microorganisms.
1.4 Explain why protozoa, algae, and nonmicrobial parasitic worms are studied in microbiology.
1.5 Differentiate prokaryotic from eukaryotic organisms.

Shortly after Leeuwenhoek made his discoveries, the Swedish botanist Carolus Linnaeus (1707–1778) developed a **taxonomic system**—a system for naming plants and animals and grouping similar organisms together. For instance, Linnaeus and other scientists of the period grouped all organisms into either the animal kingdom or the plant kingdom. Today, biologists still use this basic system, but they have modified Linnaeus's scheme by adding categories that more realistically reflect the relationships among organisms. For example, scientists no longer classify yeasts, molds, and mushrooms as plants but instead as fungi. (We examine taxonomic schemes in more detail in Chapter 4.)

▲ **FIGURE 1.3 The microbial world.** Leeuwenhoek reported seeing a scene very much like this, full of numerous fantastic, cavorting creatures.

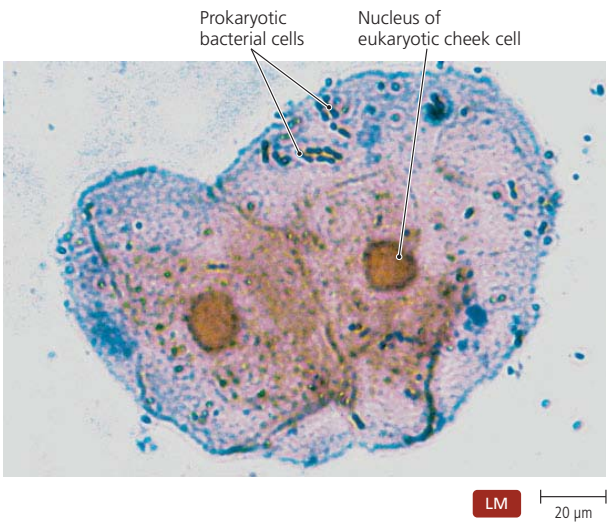
The microorganisms that Leeuwenhoek described can be grouped into six basic categories: bacteria, archaea, fungi, protozoa, algae, and small multicellular animals. The only types of microbes not described by Leeuwenhoek are *viruses*,[2] which are too small to be seen without an electron microscope. We briefly consider organisms in the first five categories in the following sections.

Bacteria and Archaea

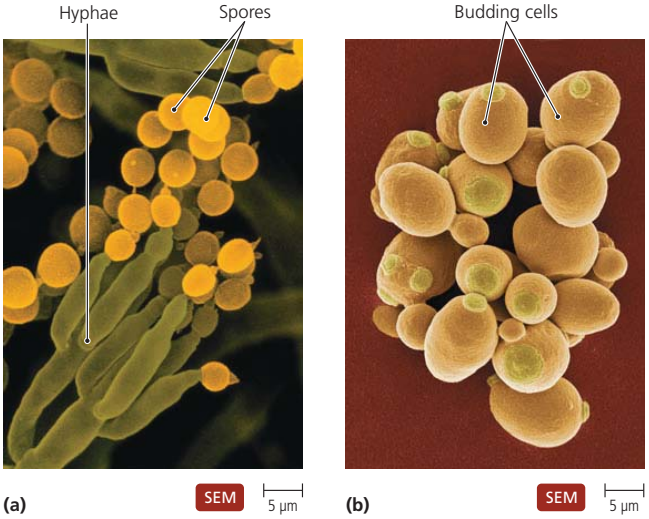
Bacteria and **archaea** are **prokaryotic**,[3] meaning that they lack nuclei; that is, their genes are not surrounded by a membrane. Bacterial cell walls are composed of a polysaccharide called *peptidoglycan*. (Some bacteria, however, lack cell walls.) The cell walls of archaea lack peptidoglycan and instead are composed of other chemicals. Members of both groups reproduce asexually. (Chapters 3, 4, and 11 examine other differences between bacteria and archaea, and Chapters 19–24 discuss pathogenic [disease-causing] bacteria.)

Most archaea and bacteria are much smaller than eukaryotic cells **(FIGURE 1.4)**. They live singly or in pairs, chains, or clusters in almost every habitat containing sufficient moisture. Archaea are often found in extreme environments, such as the highly saline and arsenic-rich Mono Lake in California, acidic

[1]The Royal Society of London for the Promotion of Natural Knowledge, granted a royal charter in 1662, is one of the older and more prestigious scientific groups in Europe.
[2]Technically, viruses are not "organisms," because they neither replicate themselves nor carry on the chemical reactions of living things.
[3]From Greek *pro*, meaning "before," and *karyon*, meaning "kernel" (which in this case refers to the nucleus of a cell).



▲ **FIGURE 1.4 Cells of the bacterium *Streptococcus* (dark blue) and two human cheek cells.** Notice the size difference.



▲ **FIGURE 1.5 Fungi. (a)** The mold *Penicillium chrysogenum*, which produces penicillin, has long filamentous hyphae that intertwine to form its body. It reproduces by spores. **(b)** The yeast *Saccharomyces cerevisiae*. Yeasts are round to oval and typically reproduce by budding.

hot springs in Yellowstone National Park, and oxygen-depleted mud at the bottom of swamps. No archaea are known to cause disease.

Though bacteria may have a poor reputation in our world, the great majority do not cause disease in animals, humans, or crops. Indeed, bacteria are beneficial to us in many ways. For example, bacteria (and fungi) degrade dead plants and animals to release phosphorus, sulfur, nitrogen, and carbon back into the air, soil, and water to be used by new generations of organisms. Without microbial recyclers, the world would be buried under the corpses of uncountable dead organisms. Without beneficial bacteria, our bodies would be much more susceptible to disease.

Fungi

Fungi (fŭn´jī)[4] cells are **eukaryotic**;[5] that is, each of their cells contains a nucleus composed of genetic material surrounded by a distinct membrane. Fungi are different from plants because they obtain their food from other organisms (rather than making it for themselves). They differ from animals by having cell walls.

Microscopic fungi include some molds and yeasts. **Molds** are typically multicellular organisms that grow as long filaments that intertwine to make up the body of the mold. Molds reproduce by sexual and asexual spores, which are cells that produce a new individual without fusing with another cell **(FIGURE 1.5a)**. The cottony growths on cheese, bread, and jams are molds. *Penicillium chrysogenum* (pen-i-sil´ē-ŭm krī-so´jĕn-ŭm) is a mold that produces penicillin.

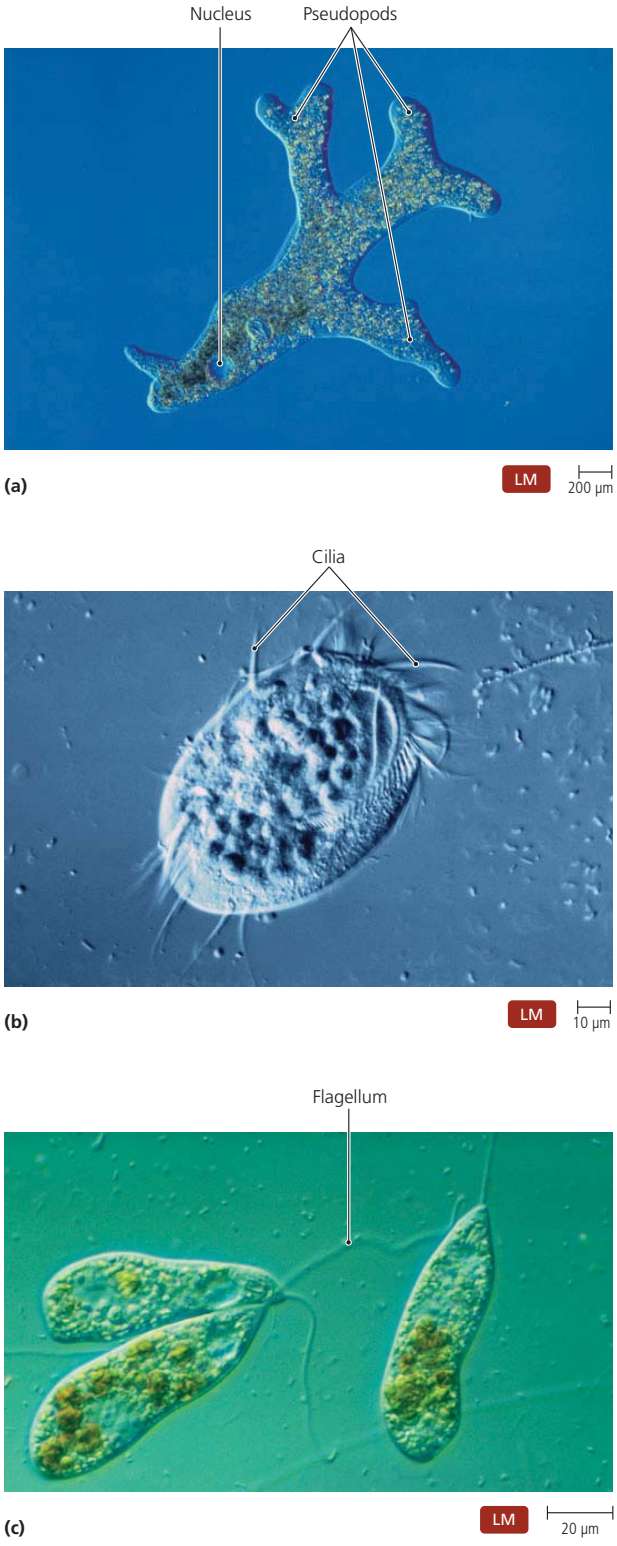
Yeasts are unicellular and typically oval to round. They reproduce asexually by *budding*, a process in which a daughter cell grows off the mother cell. Some yeasts also produce sexual spores. An example of a useful yeast is *Saccharomyces cerevisiae* (sak-ă-rō-mī´sēz se-ri-vis´ē-ī; **FIGURE 1.5b**), which causes bread to rise and produces alcohol from sugar (see **Beneficial Microbes: Bread, Wine, and Beer** on p. 7). *Candida albicans* (kan´did-ă al´bi-kanz) is a yeast that causes most cases of yeast infections in women. (Fungi and their significance in the environment, in food production, and as agents of human disease are discussed in Chapters 12 and 19–24.)

Protozoa

Protozoa are single-celled eukaryotes that are similar to animals in their nutritional needs and cellular structure. In fact, *protozoa* is Greek for "first animals," though scientists today classify them in their own groups rather than as animals. Most protozoa are capable of locomotion, and one way scientists categorize protozoa is according to their locomotive structures: *pseudopods*,[6] *cilia*,[7] or *flagella*.[8] Pseudopods are extensions of a cell that flow in the direction of travel **(FIGURE 1.6a)**. Cilia are numerous, short protrusions of a cell that beat rhythmically to propel the protozoan through its environment **(FIGURE 1.6b)**. Flagella are also extensions of a cell but are fewer, longer, and more whiplike than cilia **(FIGURE 1.6c)**. Some protozoa, such as the malaria-causing *Plasmodium* (plaz-mō´dē-ŭm), are nonmotile in their mature forms.

Protozoa typically live freely in water, but some live inside animal hosts, where they can cause disease. Most protozoa reproduce asexually, though some are sexual as well. (Chapters 12 and 19–24 further examine protozoa and some diseases they cause.)

[4]Plural of the Latin *fungus*, meaning "mushroom."
[5]From Greek *eu*, meaning "true," and *karyon*, meaning "kernel."
[6]Plural Greek *pseudes*, meaning "false," and *podos*, meaning "foot."
[7]Plural of the Latin *cilium*, meaning "eyelid."
[8]Plural of the Latin *flagellum*, meaning "whip."



▶ **FIGURE 1.6 Locomotive structures of protozoa. (a)** Pseudopods are cellular extensions used for locomotion and feeding, as seen in *Amoeba proteus*. **(b)** Cilia are short, motile, hairlike extrusions, as seen in *Euplotes*. **(c)** Flagella are whiplike extensions that are less numerous and longer than cilia, as seen in *Peranema*. *How do cilia and flagella differ?*

Figure 1.6 *Cilia are short, numerous, and often cover the cell, whereas flagella are long and relatively few in number.*

Algae

Algae[9] are unicellular or multicellular *photosynthetic* eukaryotes; that is, like plants, they make their own food from carbon dioxide and water using energy from sunlight. They differ from plants in the relative simplicity of their reproductive structures. Algae are categorized on the basis of their pigmentation and the composition of their cell walls.

Large algae, commonly called seaweeds and kelps, are common in the world's oceans. Chemicals from their gelatinous cell walls are used as thickeners and emulsifiers in many food and cosmetic products as well as in a hardening agent called *agar* in microbiological laboratory media.

Unicellular algae **(FIGURE 1.7)** are common in freshwater ponds, streams, and lakes and in the oceans as well. They are the major food of small aquatic and marine animals and provide most of the world's oxygen as a by-product of photosynthesis. The glasslike cell walls of diatoms provide grit for many polishing compounds. Manufacturers use gelatinous chemicals from the cell walls of some algae as thickeners and emulsifiers in many foods and cosmetics. Scientists use one algae-derived chemical called *agar* to solidify laboratory media. (Chapter 12 discusses other aspects of the biology of algae.)

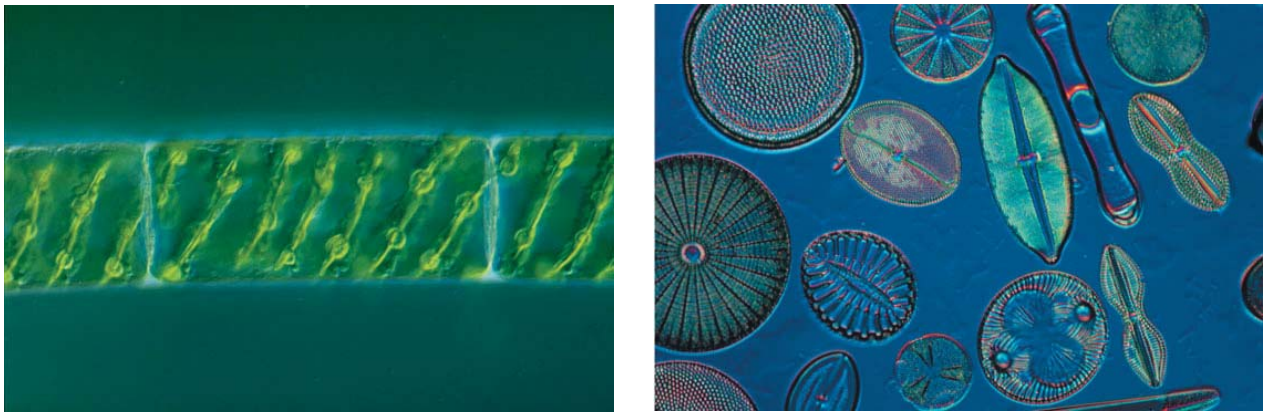
Other Organisms of Importance to Microbiologists

Microbiologists also study parasitic worms, which range in size from microscopic forms **(FIGURE 1.8)** to adult tapeworms over 7 meters (approximately 23 feet) in length. Even though most of these worms are not microscopic as adults, many of them cause diseases that were studied by early microbiologists. Further, laboratory technicians diagnose infections of parasitic worms by finding microscopic eggs and immature stages in blood, fecal, urine, and lymph specimens. (Chapters 21 and 23 discuss parasitic worms.)

The only type of microbe that remained hidden from Leeuwenhoek and other early microbiologists was the virus, which is much smaller than the smallest prokaryote and is not visible by light microscopy **(FIGURE 1.9)**. Viruses could not be seen until the electron microscope was invented in 1932. All viruses are acellular (not composed of cells) obligatory parasites composed of small amounts of genetic material (either DNA or RNA) surrounded by a protein coat. (Chapter 13 examines the general characteristics of viruses, and Chapters 18–24 discuss specific viral pathogens.)

Leeuwenhoek first reported the existence of most types of microorganisms in the late 1600s, but microbiology did not

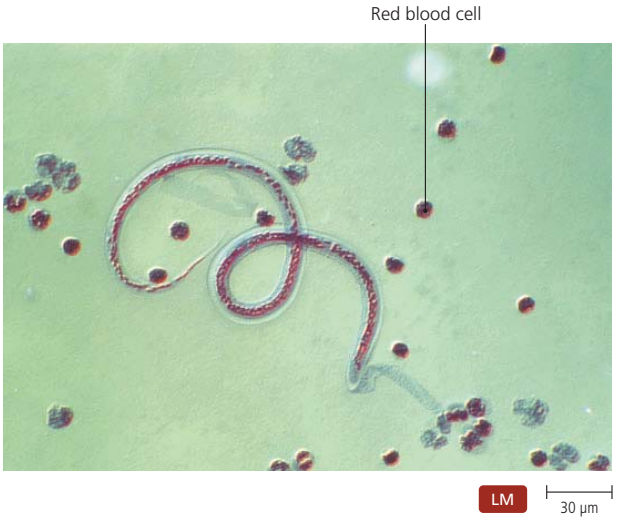
[9]Plural of the Latin *alga,* meaning "seaweed."



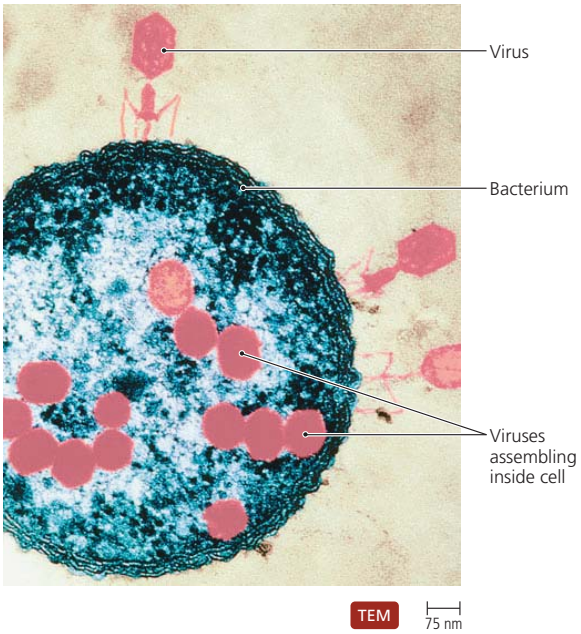
▲ **FIGURE 1.7 Algae. (a)** *Spirogyra*. These microscopic algae grow as chains of cells containing helical photosynthetic structures. **(b)** Diatoms. These beautiful algae have glasslike cell walls.

develop significantly as a field of study for almost two centuries. There were a number of reasons for this delay. First, Leeuwenhoek was a suspicious and secretive man. Though he built over 400 microscopes, he never trained an apprentice, and he never sold or gave away a microscope. In fact, he never let *anyone*—not his family or such distinguished visitors as the czar of Russia—so much as peek through his very best instruments. When Leeuwenhoek died, the secret of creating superior microscopes was lost. It took almost 100 years for scientists to make microscopes of equivalent quality.

Another reason that microbiology was slow to develop as a science is that scientists in the 1700s considered microbes to be curiosities of nature and insignificant to human affairs. But in the late 1800s, scientists began to adopt a new philosophy, one that demanded experimental evidence rather than mere acceptance of traditional knowledge. This fresh philosophical foundation, accompanied by improved microscopes, new laboratory techniques, and a drive to answer a series of pivotal questions, propelled microbiology to the forefront as a scientific discipline.



▲ **FIGURE 1.8 An immature stage of a parasitic worm in blood.**



▲ **FIGURE 1.9 A colorized electron microscope image of viruses infecting a bacterium.** Viruses, which are acellular obligatory parasites, are too small to be seen with a light microscope. Notice how small the viruses are compared to the bacterium.

TELL ME WHY

Some people consider Leeuwenhoek the "Father of Microbiology." Explain why this moniker makes sense.

The Golden Age of Microbiology

LEARNING **OUTCOME**

1.6 List and answer four questions that propelled research in what is called the "Golden Age of Microbiology."

For about 50 years, during what is sometimes called the "Golden Age of Microbiology," scientists and the blossoming field of microbiology were driven by the search for answers to the following four questions:

- Is spontaneous generation of microbial life possible?
- What causes fermentation?
- What causes disease?
- How can we prevent infection and disease?

Competition among scientists who were striving to be the first to answer these questions drove exploration and discovery in microbiology during the late 1800s and early 1900s. These scientists' discoveries and the fields of study they initiated continue to shape the course of microbiological research today.

In the next sections we consider these questions and how the great scientists accumulated the experimental evidence that answered them.

Does Microbial Life Spontaneously Generate?

LEARNING **OUTCOMES**

1.7 Identify the scientists who argued in favor of spontaneous generation.

1.8 Compare and contrast the investigations of Redi, Needham, Spallanzani, and Pasteur concerning spontaneous generation.

1.9 List four steps in the scientific method of investigation.

A dry lake bed has lain under the relentless North African desert sun for eight long months. The cracks in the baked, parched mud are wider than a man's hand. There is no sign of life anywhere in the scorched terrain. With the abruptness characteristic of desert storms, rain falls in a torrent, and a raging flood of roiling water and mud crashes down the dry streambed and fills the lake. Within hours, what had been a lifeless, dry mudflat becomes a pool of water teeming with billions of shrimp; by the next day it is home to hundreds of toads. Where did these animals come from?

Many philosophers and scientists of past ages thought that living things arose via three processes: through asexual

BENEFICIAL MICROBES

Bread, Wine, and Beer

Microorganisms play important roles in people's lives; for example, pathogens have undeniably altered the course of history. However, what may be the most important microbiological event—one that has had a greater impact on culture and society than that of any disease or epidemic—was the domestication of the yeast used by bakers and brewers. Its name, *Saccharomyces cerevisiae*, means "sugar fungus [that makes] beer."

The earliest record of the use of yeast comes from Persia (modern Iran), where archaeologists have found the remains of grapes and wine preservatives in pottery vessels more than 7000 years old. Brewing of beer likely started even earlier, its beginnings undocumented. The earliest examples of leavened bread are from Egypt and show that bread making was routine about 6000 years ago. Before that time, bread was unleavened and flat.

It is likely that making wine and brewing beer occurred earlier than the use of leavened bread because *Saccharomyces* is naturally found on grapes, which can begin to ferment while still on the vine. Historians hypothesize that early bakers may have exposed bread dough to circulating air, hoping that the invisible and inexplicable "fermentation principle" would inoculate the bread. Another hypothesis is that bakers learned to add small amounts of beer or wine to the bread, intentionally inoculating the dough with yeast. Of course, all those years before Leeuwenhoek and Pasteur, no one knew that the fermenting ingredient of wine was a living organism.

Besides its role in baking and in making alcoholic beverages, *S. cerevisiae* is an important tool for the study of cells. Scientists use yeast to delve into the mysteries of cellular function, organization, and genetics, making *Saccharomyces* the most intensely studied eukaryote. In fact, molecular biologists published the complete sequence of the genes of *S. cerevisiae* in 1996—a first for any eukaryotic cell.

Today, scientists are working toward using *S. cerevisiae* in novel ways. For example, some nutritionists and gastroenterologists are examining the use of *Saccharomyces* as a *probiotic*, that is, a microorganism intentionally taken to ward off disease and promote good health. Research suggests that the yeast helps treat diarrhea and colitis and may even help prevent these and other gastrointestinal diseases.