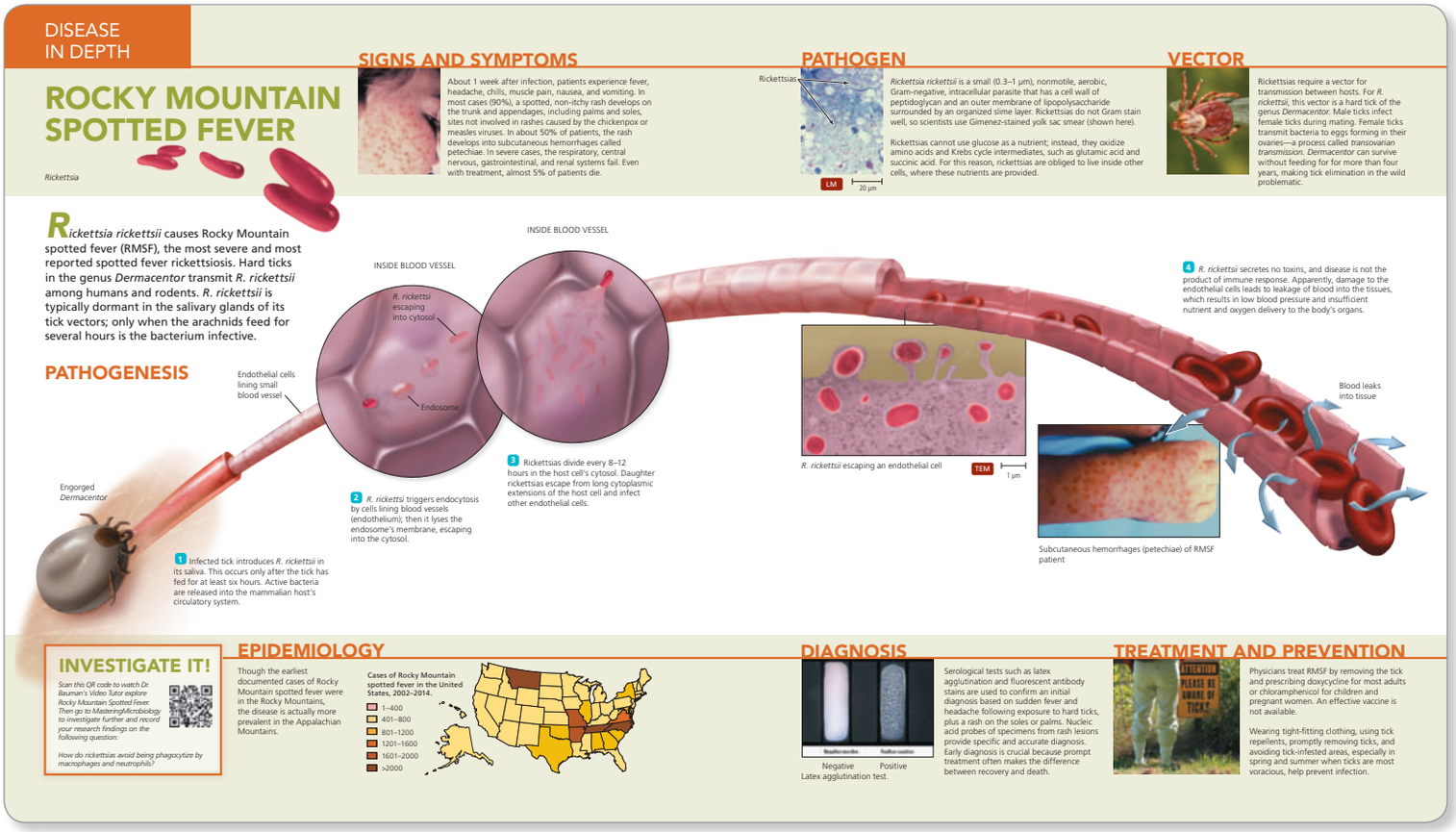
5th Edition

MICRO BIOLOGY

WITH DISEASES BY TAXONOMY

ROBERT W. BAUMAN

NEW! Disease in Depth One- or two-page spreads feature important and representative diseases. These highly visual spreads contain illustrations, micrographs, and infographics, providing in-depth overviews of selected diseases for comprehensive study and review.

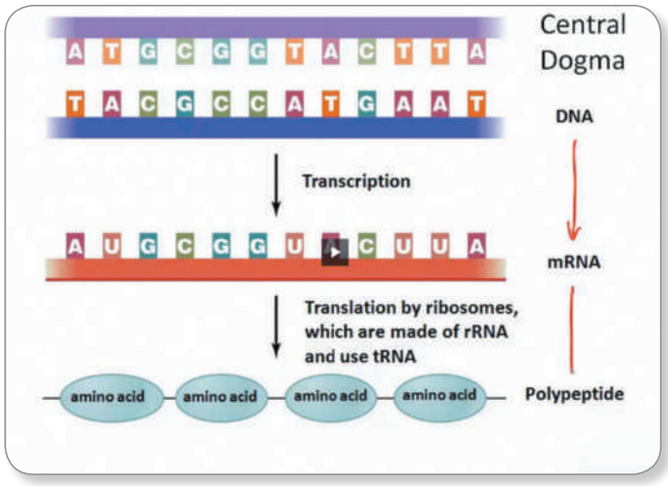


Disease in Depth Video Tutors walk through the presented disease, concluding with an "Investigate It!" question for independent research, furthering your understanding of microbiology's relevancy and importance. Dr. Bauman also includes video tutors to coach students through key process art figures in the book.

MasteringMicrobiology®

NEW! Disease in Depth Coaching Activities feature personalized hints and feedback and provide guidance through each disease, prompting students to explore further with independent research.

NEW! Connecting Concepts Coaching Activities reinforce a "big picture" understanding of microbiology by showing how concepts in a particular chapter connect across other chapters in the text.



Master Microbiology **at your own pace**, wherever you go!

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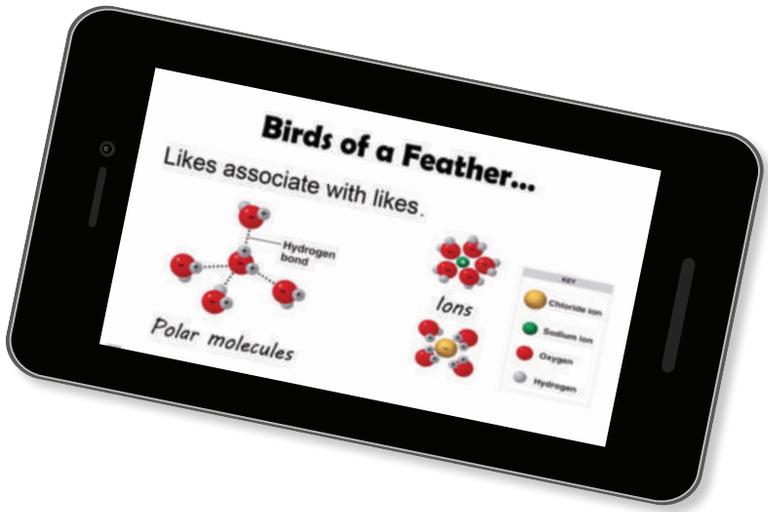
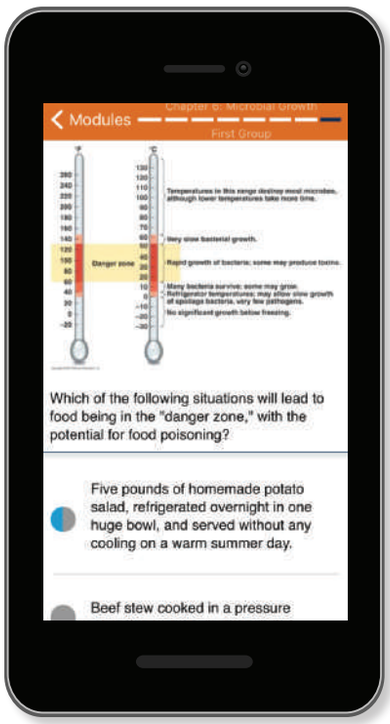
NEW! MicroBoosters offer a mobile-friendly way for you to review (or learn for the first time) foundational concepts that are important in order to understand Microbiology, including Study Skills, Basic General and Organic Chemistry, Cell Biology, and more. MicroBoosters can be assigned through MasteringMicrobiology and are available for self-study as Dynamic Study Modules.





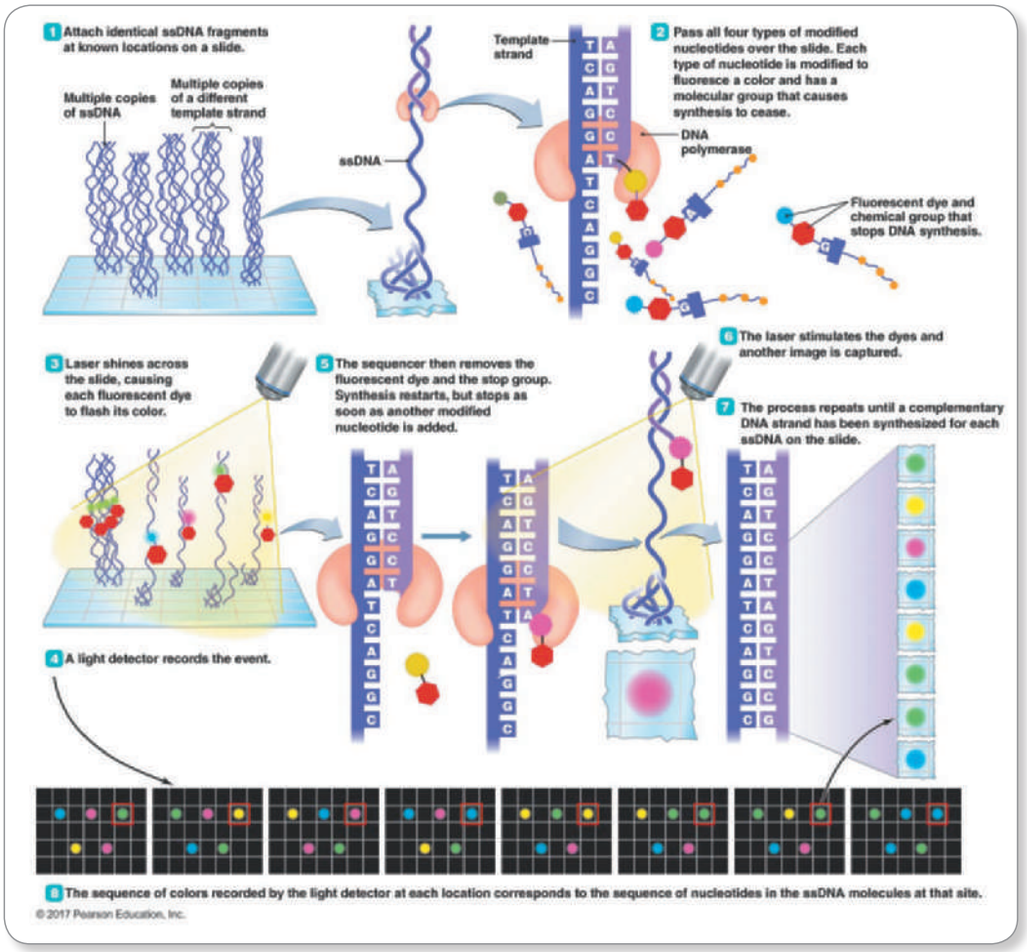
NEW! Mobile-friendly Dynamic Study Modules help students acquire, retain, and recall information faster and more effectively than ever before. These flashcard-style modules are available as a self-study tool or can be assigned by instructors.

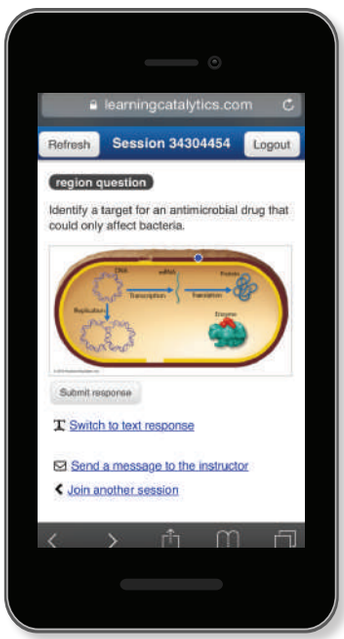
NEW! Adaptive Follow-Up Assignments in MasteringMicrobiology are based on each student's performance on the original homework assignment and, when assigned, provide additional coaching and practice.

EXPANDED! Dr. Bauman's Video Tutors, developed and narrated by the author, carefully teach key concepts using textbook art, bringing the illustrations to life and helping you visualize and understand complex topics and important processes. The Fifth Edition includes new video tutors on key concepts as well as the Disease in Depth overviews. You can quickly access the video tutors by scanning QR codes with a mobile device for on-the-go tutoring; instructors may also assign them as coaching activities in MasteringMicrobiology.

Learn how **today's microbiologists think.**

UPDATED! Every chapter has been revised to reflect the current **State of the Science**, including the latest research and technology. Highlights of content updates include extensive discussions on the impact of genomics in understanding disease diagnosis and treatment options.





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NEW! ASM Curriculum Guidelines pre-test and post-test assessments are assignable in MasteringMicrobiology to facilitate efficient and customizable assessment of the six underlying concepts and 22 related topics of lasting importance in undergraduate microbiology courses as determined by the American Society of Microbiology.

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- ELISA
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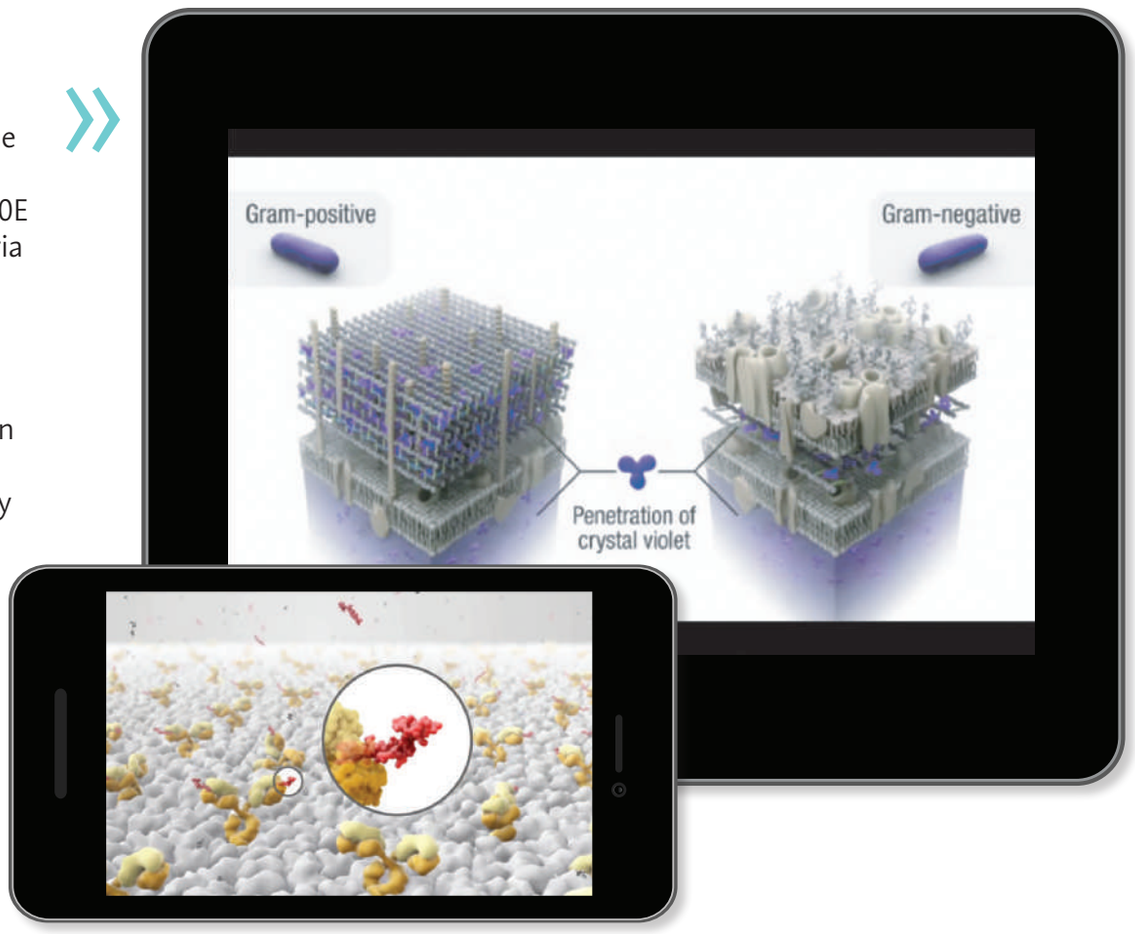
- Polymerase Chain Reaction (PCR)
- Safety in the Microbiology Laboratory
- Quantifying Bacteria with Serial Dilutions and Pour Plates
- Smear Preparation and Fixation
- Streak Plate Technique
- Survey of Protozoa
- Identification of Unknown Bacteria



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- **NEW!** How to Write a Lab Report
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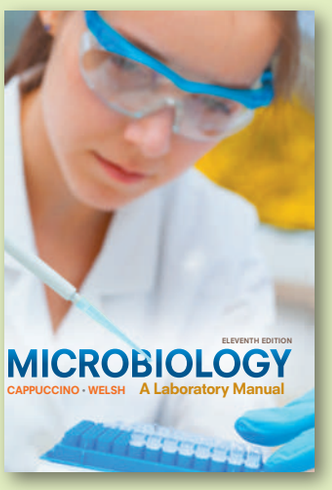
- Carbohydrate Catabolism
- Compound Microscope
- Differential and Selective Media
- Disk-Diffusion Assay
- ELISA
- Gram Stain
- Hydrogen Sulfide Production
- Litmus Milk Reactions
- Negative Staining
- Respiration
- Serial Dilutions
- Simple Staining
- Smear Preparation
- Structural Stains
- Safety in the Microbiology Laboratory

Also Available for the Microbiology Lab Course



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by Robert W. Bauman, Nichol Dolby

The Fifth Edition Test Bank includes hundreds of multiple choice, true/false, and short answer/essay questions that are correlated to the book's Learning Outcomes and Bloom's Taxonomy rankings. Available electronically in the "Instructor Resources" area of MasteringMicrobiology, in both Microsoft Word® and in TestGen formats.

Instructor's Manual (Download Only)

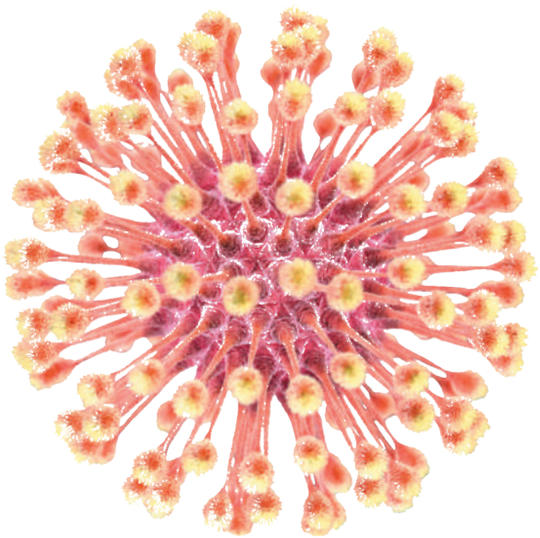
by Robert W. Bauman, Nichol Dolby

This guide can be downloaded from the "Instructor Resources" area of MasteringMicrobiology and includes a detailed chapter outline and summary for each chapter as well as answers to in-text Clinical Case Studies, "Tell Me Why" questions, Critical Thinking questions, and end-of-chapter Questions for Review.

FIFTH EDITION

MICROBIOLOGY

WITH DISEASES BY TAXONOMY



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

—Robert

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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 has taught 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 and he has been nominated for the one-time award every year since. 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), environmentally triggered chromogenesis in butterflies, and terrestrial oil pollution remediation by naturally occurring bacteria. He is a member of the American Society of Microbiology (ASM) where he has held national offices, Texas Community College Teachers Association (TCCTA) where he serves in a statewide position of leadership, 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, skiing, and reading by a crackling fire in the winter and in a gently swaying hammock in the summer.

TODD P. PRIMM (contributor) is an associate professor at Sam Houston State University, where he teaches pre-nursing microbiology. He also serves as Director of the Professional and Academic Center for Excellence, which focuses on improving teaching and learning on campus. In 2010, he was Distinguished Alumnus of the Graduate School of Biomedical Sciences of Baylor College of Medicine, where he earned a Ph.D. in Biochemistry in 1997. He received a B.S. from Texas A&M University in 1992. He is very active in the American Society for Microbiology and received the Texas Branch 2015 Faculty Teaching Award. He was chair of the organizing committee for the 2013 ASM Conference for Undergraduate Educators, participated in the 2012 Research Residency of the ASM/NSF Biology Scholars Program, and currently serves on the editorial board for the *Journal of Microbiology and Biology Education*. He is also an affiliate staff member with the international organization Cru. He loves teaching and mentoring students and spending time with his wonderful wife of 23 years and four children.

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.

JEAN E. MONTGOMERY is a registered nurse formerly teaching in the associate degree nursing program at Austin Community College in Texas. She received her MSN from the University of Texas Health Science Center at San Antonio, Texas.

Preface

The reemergence of whooping cough, mumps, and measles and the emergence of snail fever, spotted fever rickettsiosis, Middle East respiratory syndrome, and other 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 27 years and witnessed firsthand how students struggle with the same topics and concepts year after year. To address these challenging topics, I have created 14 new Video Tutors: three in addition to those already incorporated into the first 18 chapters of the text and 11 that cover the Disease in Depth features. 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 aim 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 fifth 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 Microbe at a Glance features have been widely praised by instructors and students, so I, along with art editor Kelly Murphy, developed 11 new Disease in Depth features, most as two-page spreads, that use compelling art and photos to provide a detailed, visually unsurpassed overview of a specific disease. Each Disease in Depth feature includes an Investigate It! question with a QR code directing students to a Video Tutor that explores the topic and encourages further, independent research. These activities are assignable in MasteringMicrobiology®. Another goal for this edition was to provide additional instruction on important foundational concepts and processes. To that end, I developed and narrated three new core concept Video Tutors, accessible via QR codes in the textbook and assignable 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** features highlight important and representative diseases for each body system, extending the visual impact of the art program as well as the highly praised Microbe at a Glance features. Each of these 11 visual features contains infographics, provides in-depth coverage of the selected disease, and includes a QR code and Investigate It! question that directs students to a Video Tutor exploring the topic and prompting further inquiry and critical thinking.

New assignable Disease in Depth coaching activities in MasteringMicrobiology® 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. New to this edition are Video Tutors on glycolysis, protein translation, and antigen processing. These Video Tutors bring the textbook art to life and help students visualize and understand tough topics and important processes. Thirty-two 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 the Disease in Depth features.
- **The genetics chapters (Chapters 7–8)** have been reviewed and revised by genetics specialists. These now reflect the most current understanding of this rapidly evolving field, including new discussion of next-generation DNA sequencing.
- **Over 330 NEW and revised micrographs, photos, and figures** enhance student understanding of the text and boxed features.
- **NEW and EXPANDED MasteringMicrobiology** includes new Interactive Microbiology animations and tutorials; new MicroBooster remedial video tutorials; new Disease in Depth coaching activities; new Video Tutors with assessments; new MicroCareers and Clinical Case Study coaching activities; and a plethora of microbiology lab resources. **NEW** Interactive Microbiology is a dynamic suite of interactive tutorials and animations that teach key concepts in the context of a clinical setting. Students actively engage with each topic and learn from manipulating variables, predicting outcomes, and answering formative and summative assessments. Topics include Operons; Complement; Biofilms and Quorum Sensing; Antibiotic Resistance, Mechanisms; Antibiotic Resistance, Selection; Aerobic Respiration in Prokaryotes; and Human Microbiota. **NEW** MicroBoosters are a suite of brief video tutorials that cover key concepts that students often need to review, including Study Skills, Math, Basic Chemistry, Cell Biology, Basic Biology and more! The Micro Lab resources include MicroLab Tutors, which use lab technique videos, 3-D molecular animations, and step-by-step tutorials to help students make connections between lecture and lab; Lab Technique Videos and pre-lab quizzes to ensure that students come prepared for lab time; and Lab Practical and post-lab quizzes to reinforce what students have learned.

MasteringMicrobiology offers students access to Dynamic Study Modules to help them acquire, retain, and recall information faster and more efficiently than ever before with textbook-specific explanations and art. Dynamic Study Modules are available for use as a self-study tool or as assignments. Instructors also now have the option to give Adaptive Follow-Up assignments that provide student-specific additional coaching and practice. These question sets continuously adapt to each student's needs, making efficient use of homework time.

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

Chapter-by-Chapter Revisions

CHAPTER 1 A BRIEF HISTORY OF MICROBIOLOGY

- Added three Tell Me Why critical thinking questions to text
- Added three new photos (chapter opener, Fig. 1.6b, Highlight box on MERS)
- Updated map showing countries having transmission of variant Creutzfeldt-Jakob disease (vJCD)
- Added CDC-preferred term "healthcare-associated infection (HAI)" (formerly nosocomial infection)
- Added introductory coverage of normal microbiota and of agar in micro labs
- Clarified the use of *controls* in Pasteur's experiment to disprove spontaneous generation
- Clarified industrial use of microbes in making yogurt and pest control
- Introduced the success of gene therapy to treat several inherited immune deficiencies
- Updated box: "The New Normal": The Challenge of Emerging and Reemerging Diseases to include Middle East respiratory syndrome (MERS), Ebola, chikungunya, and measles
- Added to list of current problems in microbiology: biofilms, tests for infections, and persistent antimicrobial-drug resistance
- Added three critical thinking questions to Emerging Disease Case Study: Variant Creutzfeldt-Jacob Disease
- New end-of-chapter, short-answer question on healthcare-associated (nosocomial) infections
- Added fill-in Concept Map over types of microbes and some of their major characteristics

CHAPTER 2 THE CHEMISTRY OF MICROBIOLOGY

- Added five Tell Me Why critical thinking questions to text
- Eleven figures revised for better pedagogy (Figs. 2.2, 2.3, 2.6, 2.11, 2.15, 2.17, 2.19, 2.21, 2.22, 2.23; amino group in Table 2.3)
- New Learning Outcomes concerning terms regarding elements, valence electrons and chemical bonding, organic compounds, contrasting ionic and covalent bonds, and lipids
- New figure legend question for enhanced pedagogy (Fig. 2.3)
- Expanded coverage of term "nucleoside" because nucleoside analogs treat many diseases
- Added fill-in Concept Map over nucleotide structure and function

CHAPTER 3 CELL STRUCTURE AND FUNCTION

- Added 12 Tell Me Why critical thinking questions to text
- Two new photos (Figs. 3.5b, 3.8a)
- Revised and enhanced artwork in 14 figures for enhanced pedagogy (Figs. 3.4, 3.8b, 3.9, 3.12, 3.14, 3.15, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.24, 3.35)
- Added one new figure (structure of glucose versus NAG and NAM) (Fig. 3.13)
- Enhanced discussion of flagella and cilia structure and function, comparison and contrast between the outer and cytoplasmic membranes of Gram-negative cells, and movement across cell membranes

CHAPTER 4 MICROSCOPY, STAINING, AND CLASSIFICATION

- Added four Tell Me Why critical thinking questions to text
- Revised two figures for enhanced pedagogy (Figs. 4.4, 4.6)
- Revised Learning Outcome regarding simple stains, which now include Gomori methenamine silver stain and hematoxylin and eosin stains
- Added fill-in-the-blank Concept Map about Gram stain and cell wall structure to end-of-chapter review
- Revised coverage of history of taxonomy
- Expanded discussion of resolution, immersion oil, mordants, definition of microbial species, and role of George Fox in the discovery of the archaea and three domains of life
- Revised section on microbial taxonomy to more fully address genomic techniques in taxonomy
- At request of reviewers and instructors, removed detailed figures for dark field, phase, and scanning electron microscopy so as to reduce complexity and chapter length
- Added three critical thinking questions and a new photo to Emerging Disease Case Study: Necrotizing Fasciitis

CHAPTER 5 MICROBIAL METABOLISM

- Added six Tell Me Why critical thinking questions to text
- Added two new figure questions (Figs. 5.4, 5.13)
- Added one new end-of-chapter fill-in-the-blank question
- Revised 14 figures for greater clarity and better pedagogy (Figs. 5.5, 5.6, 5.10, 5.11, 5.12, 5.13, 5.14, 5.16, 5.17, 5.18, 5.19, 5.26, 5.30; end-of-chapter critical thinking question 1)
- Clarified and expanded discussion of enzymatic activation through allosteric sites and competitive and noncompetitive inhibition of enzyme activity
- Added fill-in Concept Map over aerobic respiration

CHAPTER 6 MICROBIAL NUTRITION AND GROWTH

- Added three Tell Me Why critical thinking questions to text
- Revised five figures for greater clarity and better pedagogy (Figs. 6.7, 6.8, 6.9, 6.17, 6.20)
- Added two new photos (Figs. 6.13, 6.24b)
- Expanded discussion of singlet oxygen and superoxide radicals as oxidizing agents
- Clarified the method of counting microbes using a cell counter
- Added fill-in Concept Map over culture media

CHAPTER 7 MICROBIAL GENETICS

- Added four Tell Me Why critical thinking questions to text
- Upgraded 20 figures for greater clarity, accuracy, ease of reading, and better pedagogy (Figs. 7.1, 7.5, 7.6, 7.7, 7.9, 7.10, 7.11, 7.13, 7.20, 7.21, 7.22, 7.23, 7.26, 7.27, 7.28, 7.30, 7.34, 7.35, 7.36, 7.37)
- Updated text to discuss the smallest cellular genome at 112,091 bp (candidatus *Nasuia deltocephalinicola*)
- Included recent discovery that chloroplast chromosomes are linear rather than circular
- Increased discussion of use of RNA as enzymes (ribozymes)

- Expanded table comparing and contrasting DNA replication, transcription, and translation
- Discussed codon and tRNA for 21st amino acid, selenocysteine
- Enhanced and clarified discussion of *lac* and *trp* operons and of the action of cAMP and CAP as activators
- Expanded and reorganized discussion of DNA repair systems
- Clarified and updated information on the events in conjugation, particularly with Hfr cells
- Expanded coverage of nucleotides and pyrophosphate (diphosphate)
- Added critical thinking questions to Emerging Disease Case Study: *Vibrio vulnificus* Infection
- Revised the chapter to better explain differences between archaeal, bacterial, and eukaryotic genetics
- Added fill-in Concept Map over point mutations

CHAPTER 8 RECOMBINANT DNA TECHNOLOGY

- Added five Tell Me Why critical thinking questions to text
- Added six Learning Outcomes concerning uses of synthetic nucleic acids, PCR, fluorescent *in situ* hybridization (FISH), functional genomics, Sanger sequencing, and next-generation sequencing
- Added one new figure (Fig. 8.10)
- Modified Fig. 8.7 for better pedagogy
- Deleted figures for Southern blots and Sanger automated DNA sequencing as these techniques are historical and less-commonly used today
- Added discussion of real-time PCR (RT-PCR), Sanger sequencing methods, next-generation DNA sequencing (NGS), including pyrosequencing and fluorescent methods, functional genomics, microbiomes, and biomedical animal models
- New Highlight boxes: How Do You Fix a Mosquito? on controlling dengue and The Human Microbiome Project

CHAPTER 9 CONTROLLING MICROBIAL GROWTH IN THE ENVIRONMENT

- Added four Tell Me Why critical thinking questions to text
- Revised five figures for better accuracy, currency, and pedagogy (Figs. 9.2, 9.7, 9.13, 9.15, 9.16)
- Two new photos (Fig. 9.9, Beneficial Microbes)
- Updated techniques for deactivation of prions, coverage of thimerosal in vaccines, and activity of AOAC International in developing disinfection standards
- Added three critical thinking questions to Emerging Disease Case Study: *Acanthamoeba* Keratitis
- Added critical thinking question concerning salmonellosis pandemic from smoked salmon
- Added fill-in Concept Map over moist heat applications to control microbes

CHAPTER 10 CONTROLLING MICROBIAL GROWTH IN THE BODY: ANTIMICROBIAL DRUGS

- Added four Tell Me Why critical thinking questions to text
- Updated and revised tables of antimicrobials to include all new antimicrobials mentioned in disease chapters, including carbapenems and capreomycin (antibacterials); enfuvirtide (newly approved anti-HIV-1); ciclopirox (antifungal); and bithionol (anthelmintic); updated sources of drugs, modes of action, clinical considerations, and methods of resistance
- Updated adverse effects of aminoglycosides
- Updated the mechanism of resistance against quinolone antibacterial drugs
- Removed amantadine as a treatment for influenza A
- Revised seven figures for greater clarity, accuracy, ease of reading, and better pedagogy (Figs. 10.2, 10.3, 10.6, 10.8, 10.13, 10.15; map of worldwide, community-associated MRSA)
- Three new photos (Highlight, Fig. 10.10, Clinical Case Study)
- Added three critical thinking questions to Emerging Disease Case Study: Community-Associated MRSA and updated map with newly published data

CHAPTER 11 CHARACTERIZING AND CLASSIFYING PROKARYOTES

- Added four Tell Me Why critical thinking questions to text
- Six new Learning Outcomes (for proteobacteria, including newly discovered zetaproteobacteria)
- Thirteen new photos (Figs. 11.1, 11.2a, 11.5, 11.7, 11.11a, 11.16, 11.17, 11.19, 11.21, 11.22, 11.23, 11.24b, 11.27b)
- Ten revised figures for better pedagogy (Figs. 11.1, 11.3, 11.4, 11.6, 11.10, 11.14, 11.17, 11.21, 11.26, 11.27)
- Clarified and expanded coverage of (1) "snapping division," which is a distinctive characteristic of corynebacteria, including *C. diphtheriae*, (2) floc formation and its use in sewage treatment, and (3) methicillin-resistant strains of *Staphylococcus aureus*
- Updated with new discoveries in bacterial and archaeal systematics: six classes of proteobacteria rather than four and five phyla of archaea (rather than two)
- Removed box on Botox and box on the possible link between cyanobacteria and brain disease to make room for new material
- Three new critical thinking questions over pertussis as a reemerging disease
- Added fill-in Concept Map over domain Archaea

CHAPTER 12 CHARACTERIZING AND CLASSIFYING EUKARYOTES

- Added six Tell Me Why critical thinking questions to text
- Eight new photos (Figs. 12.11, 12.12a and b, 12.13c, 12.14, 12.20, 12.25, 12.27)
- Seven revised figures for more accurate and lucid pedagogy (Figs. 12.1, 12.3, 12.7, 12.8, 12.17, 12.23; map for aspergillosis)
- As reviewers requested, shortened chapter by eliminating detailed discussion and artwork of ciliate (*Paramecium*) conjugation and of sexual reproduction by zygomycetes, ascomycetes, and basidiomycetes
- Updated algal, fungal, protozoan, water mold, and slime mold taxonomy
- Clarified and expanded coverage of (1) meiosis, (2) alveoli in protists, and (3) use of radiation as an energy source for some fungi
- Added new critical thinking questions: three about the emerging disease aspergillosis and two at end of chapter about genomics in relationship to metabolism in various environments
- Added fill-in Concept Map over eukaryotic microorganisms

CHAPTER 13 CHARACTERIZING AND CLASSIFYING VIRUSES, VIROIDS, AND PRIONS

- Added four Tell Me Why critical thinking questions to text
- Four new photos (Figs. 13.1b, 13.21, 13.24; bacteriophage box)
- Upgraded eight figures for better pedagogy and currency (Figs. 13.5, 13.8, 13.12, 13.13, 13.14, 13.16, 13.18, 13.22)
- One new figure showing prion templating (Fig. 13.23)
- Two new Learning Outcomes concerning (1) structures of viruses and (2) control of prions
- Updated viral nomenclature to correspond to changes approved by the International Committee on Taxonomy of Viruses (ICTV) in 2014

- Added discussion on the benefits and costs to a virus of having an envelope versus being naked
- Clarified and expanded text concerning lytic cycle of phage replication; use of phage typing; replication of animal viruses, particularly ssDNA viruses; link between viruses and human cancers; viroids; and prions
- Updated techniques for deactivation of prions and treatment of prion disease
- Updated Emerging Disease Case Study: Chikungunya; added three critical thinking questions to the discussion

CHAPTER 14 INFECTION, INFECTIOUS DISEASES, AND EPIDEMIOLOGY

- Added eight Tell Me Why critical thinking questions to text
- Changed eight figures for better pedagogy, timeliness, or clarity (Figs. 14.3, 14.4, 14.5, 14.9, 14.10, 14.14, 14.16, 14.20)
- Revised and updated coverage of (1) number of human cells in a body and the number of cellular microbiota, (2) microbiome, and (3) symbioses (added terms *symbiont* and *amensalism*)
- Updated to replace term *nosocomial* with *healthcare-associated* (in all chapters)
- Updated epidemiology charts, tables, and graphs
- Updated list of nationally notifiable infectious diseases
- Three new critical thinking questions added to the discussion of *Hantavirus* as an emerging disease
- Added fill-in Concept Map over transmission of diseases

CHAPTER 15 INNATE IMMUNITY

- Added two Tell Me Why critical thinking questions to text
- Modified nine figures for enhanced clarity and better pedagogy (Figs. 15.4, 15.6, 15.7, 15.8, 15.9, 15.11, 15.12, 15.13, 15.14)
- Three new photos (Figs. 15.1, 15.5b)
- Updated and expanded coverage of the action of antimicrobial peptides (defensins), Toll-like receptor 10 (TLR10), complement activation, complement cascade, and membrane attack complexes
- Expanded and clarified discussion of inflammatory mediators

CHAPTER 16 SPECIFIC DEFENSE: ADAPTIVE IMMUNITY

- Added three Tell Me Why critical thinking questions to text
- Revised and clarified (1) function and structure of tonsils, (2) flow of lymph, and (3) mucosa-associated lymphoid tissue
- Reordered the discussion of topics in adaptive immunity to better align with the way events occur; for example, MHC and antigen processing are discussed before T cells and cell-mediated immunity, which are discussed before B cells and antibody-mediated immunity
- Removed discussion of T-independent antibody immunity as it was too advanced for beginning students
- Revised three pieces of art for enhanced pedagogy (Figs. 16.2, 16.3, 16.10)
- Added three critical thinking questions and updated incidence map for the discussion of microsporidiosis
- Added fill-in Concept Map over antibodies

CHAPTER 17 IMMUNIZATION AND IMMUNE TESTING

- Added a Tell Me Why critical thinking question to text
- Updated to newly revised CDC 2015 vaccination schedule for children, adolescents, and adults
- Updated table of vaccine-preventable diseases in the United States
- Enhanced discussion of development of attenuated viral vaccines
- Added two points to chapter summary about recombinant gene technology and vaccine production and about vaccine safety
- Revised five figures for better pedagogy (Figs. 17.2, 17.3, 17.6, 17.11, 17.14)

CHAPTER 18 HYPERSENSITIVITIES, AUTOIMMUNE DISEASES, AND IMMUNE DEFICIENCIES

- Added three Tell Me Why critical thinking questions to text
- Revised one figure for greater clarity and accuracy (Fig. 18.7)
- Expanded coverage of type III hypersensitivity, the relationship between hypersensitivities and autoimmune disorders
- Removed figure and text for a very rare disease, immune thrombocytopenic purpura, to make room for new material in Chapter 19

CHAPTER 19 PATHOGENIC GRAM-POSITIVE BACTERIA

- Added nine Tell Me Why critical thinking questions to text
- Added three Disease in Depth visual presentations of disease: necrotizing fasciitis, listeriosis, and tuberculosis
- Twenty-five new photos (Figs. 19.1, 19.12, 19.17, 19.19, 19.20, 19.21)
- Seven revisions to figures for consistency, currency, accuracy, and better pedagogy (Figs. 19.5, 19.23; Disease in Depth: Necrottizing Fasciitis, Listeriosis, and Tuberculosis; Microbe at a Glance: *Streptococcus* and *Clostridium*)
- Updated all diagnoses and incidence data
- Revised two Learning Outcomes for better pedagogy (19.10, 19.13)
- Revised Chapter Summary for better pedagogy (for *Staphylococcus*; *Streptococcus*; *Enterococcus*, *Bacillus*; *Clostridium*; *Listeria*; *Mycoplasma*; *Corynebacterium*; *Mycobacterium*)
- Updated definitions for multi-drug-resistant (MDR) and extensively drug-resistant (XDR) tuberculosis
- Updated treatment regimen for inhalation anthrax, bioterrorist anthrax, botulism, tetanus, listeriosis, mycoplasmal pneumonia, nongonococcal urethritis, and tuberculosis
- Updated and enhanced discussion of mycolic acids, role of *Streptococcus mutans* in tooth decay, and anthrax vaccine
- Added a figure question regarding snapping division in corynebacteria
- Added three critical thinking questions and updated incidence maps for the discussion of Buruli ulcer
- Added Clinical Case Study regarding tuberculosis

CHAPTER 20 PATHOGENIC GRAM-NEGATIVE COCCI AND BACILLI

- Added three Tell Me Why critical thinking questions to text
- Added one Disease in Depth visual presentation of disease on urinary tract infections
- Updated all diagnoses and incidence data, including maps
- Updated to replace term *nosocomial* with *healthcare-associated*
- Revised Chapter Summary for better pedagogy (Pathogenic, Gram-Negative, Facultatively Anaerobic Bacilli; Pathogenic, Gram-Negative, Aerobic Bacilli; Pathogenic, Gram-Negative, Anaerobic Bacilli)
- Updated treatment regimen for gonorrhea, meningococcus meningitis, bubonic plague, bartonellosis, brucellosis, and Legionnaires' disease
- Added one new figure (Fig. 20.1) and figure question on the potential effects of lipid A
- Revised nine figures for better pedagogy (Microbe at a Glance: *Neisseria gonorrhoeae;* Figs. 20.2, 20.3, 20.14, 20.18, 20.19, 20.22, 20.23, 20.28)
- Added three critical thinking questions and updated incidence maps for the discussion of melioidosis

CHAPTER 21 RICKETTSIAS, CHLAMYDIAS, SPIROCHETES, AND VIBRIOS

- Added three Tell Me Why critical thinking questions to text
- New Disease in Depth: Spotted Fever Rickettsiosis
- Updated all diagnoses and incidence data
- Modified/updated nine figures (Figs. 21.1, 21.2, 21.3, 21.5, 21.8, 21.12, 21.13, 21.17, 21.20)
- Two new photos (Figs. 21.11, 21.19)
- Updated treatment regimen for rickettsial spotted fever (Rocky Mountain spotted fever, RMSF), murine typhus, scrub typhus, human monocytic ehrlichiosis, anaplasmosis (formerly called human granulocytic ehrlichiosis), lymphogranuloma venereum, trachoma, cholera, and gastric ulcers
- Updated and expanded coverage of epidemic typhus, murine typhus, scrub typhus, spotted fever rickettsioses (RMSF), ehrlichiosis, anaplasmosis, lymphogranuloma venereum, urethritis, yaws, *Borrelia*, and cholera

CHAPTER 22 PATHOGENIC FUNGI

- Added five Tell Me Why critical thinking questions to text
- Added new Disease in Depth: Candidiasis
- Updated all diagnoses and incidence data
- New Learning Outcomes: antifungal vaccines, mycetomas
- Added two new photos for enhanced pedagogy (Figs. 22.12, 22.20)
- Updated treatment regimen for paracoccidioidomycosis, *Pneumocystis* pneumonia, candidiasis, aspergillosis, *Malassezia* infections, mycetoma, and sporotrichosis
- Enhanced discussion of dearth of antifungal vaccines
- Added three critical thinking questions and updated incidence maps for the discussion of blastomycosis
- Added fill-in Concept Map over systemic mycoses

CHAPTER 23 PARASITIC PROTOZOA, HELMINTHS, AND ARTHROPOD VECTORS

- Added four Tell Me Why critical thinking questions to text
- Added two new Disease in Depth spreads: Giardiasis and Malaria
- Rearranged the chapter to cover vectors first; expanded coverage of vectors
- New Learning Outcomes: parasitology, definitive versus intermediate hosts, biological versus mechanical vectors, ascariasis, hookworm infestations, pinworms, anisakiasis
- Updated all diagnoses and incidence data
- Updated treatment regimen for *Acanthamoeba* keratitis, leishmaniasis, trichomoniasis, malaria, *Cryptosporidium* enteritis, and infestation with *Fasciola*
- Added mention of emerging human pathogen of malaria: *Plasmodium knowlesi*
- Updated stages in life cycle of *Toxoplasma*
- Simplified discussion of life cycles of *Trypanosoma cruzi* and of *T. brucei*
- Added roundworm *Anisakis* and its disease anisakiasis at teachers' requests
- Twenty-four new, more engaging photos (Figs. 23.2, 23.10, 23.12, 23.13, 23.18; Disease in Depth: Giardiasis; Disease in Depth: Malaria; Emerging Disease Case Study: Babesiosis)
- Eight revised, updated, enhanced, and pedagogically more effective figures (Figs. 23.1, 23.3, 23.5, 23.6, 23.9, 23.14, 23.17, 23.24)
- Added three critical thinking questions and updated incidence maps for the discussions of babesiosis and of schistosomiasis
- Added fill-in Concept Map over intestinal protozoan parasites

CHAPTER 24 PATHOGENIC DNA VIRUSES

- Added five Tell Me Why critical thinking questions to text
- Updated all diagnoses and incidence data
- Updated treatment regimen for shingles, history of smallpox vaccination, and the effect of adenovirus 36 on obesity
- Four new photos (Figs. 24.3, 24.15, 24.16c, 24.22)
- Reformatted one figure for better pedagogy (Fig. 24.21)
- Added three critical thinking questions and updated incidence maps for the discussion of monkeypox
- New Disease in Depth: Papillomas with three new photos and three new figures

CHAPTER 25 PATHOGENIC RNA VIRUSES

- Added six Tell Me Why critical thinking questions to text
- Updated all diagnoses and incidence data
- Updated treatment regimen for colds, hepatitis E, hepatitis C, AIDS, measles, respiratory syncytial virus infection, and Lassa hemorrhagic fever
- Updated, revised, and expanded discussion of coronavirus respiratory syndromes, Nipah virus encephalitis, hepatitis E virus, and respiratory syncytial viral disease
- Clarified definition of zoonosis
- Added Learning Outcome about mumps
- Sixteen figures revised, updated, or enhanced for better pedagogy (Figs. 25.2, 25.9, 25.10, 25.11, 25.12, 25.14, 25.17, 25.18, 25.19, 25.21, 25.23, 25.24, 25.26, 25.28, 25.29, 25.36)
- Thirteen new photos (chapter opener; Figs. 25.1, 25.7, 25.16b, 25.22b, 25.27, 25.30, 25.32; Highlight box on bats and Nipah virus)
- New Microbe at a Glance box on measles virus
- Two new Emerging Disease Case Study boxes on norovirus gastroenteritis and tick-borne encephalitis
- Two new Disease in Depth features on Ebola hemorrhagic fever and influenza
- Added three critical thinking questions to the box on influenza H1N1

CHAPTER 26 INDUSTRIAL AND ENVIRONMENTAL MICROBIOLOGY

- Added four Tell Me Why critical thinking questions to text
- Added Learning Outcome on eutrophication
- Three figures revised, updated, or enhanced for better pedagogy (Figs. 26.6, 26.8, 26.15)
- Revised and clarified water contamination and water pollution
- Updated list of bioterrorist threats to include the additions to category C
- New Emerging Disease Case Study regarding primary amebic meningoencephalitis (*Naegleria fowleri* infection)

Reviewers for the **Fifth 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 fifth edition, I extend my deepest appreciation to the following reviewers.

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Robert W. Bauman
Amarillo, Texas

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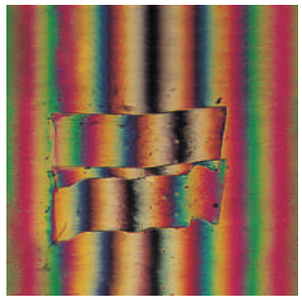

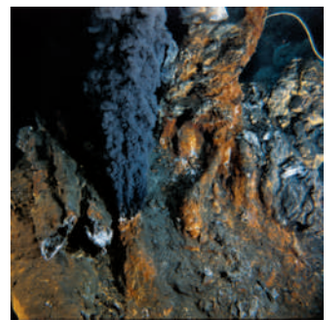

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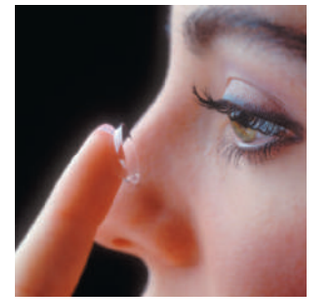

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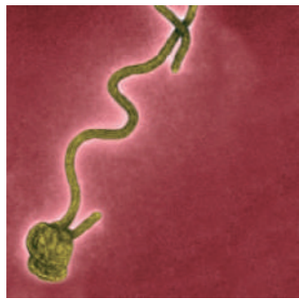

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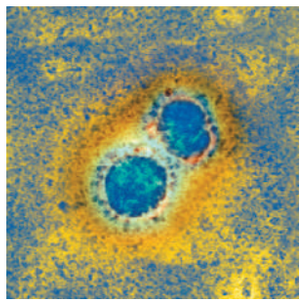

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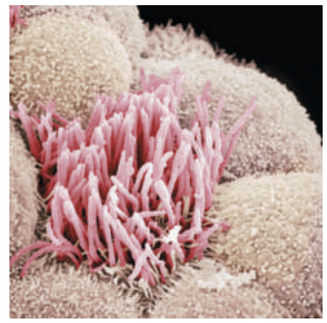

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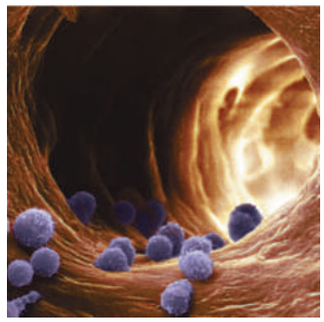

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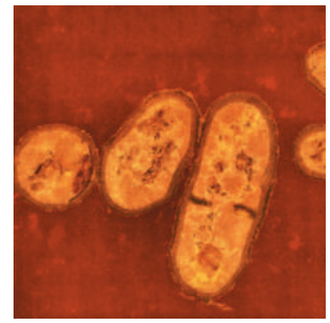
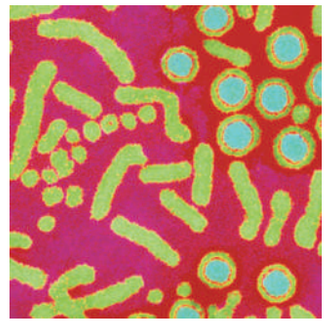
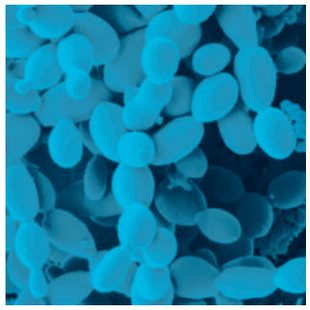






Feature Boxes

BENEFICIAL MICROBES

HIGHLIGHT

EMERGING DISEASE CASE STUDY

CLINICAL CASE STUDY

MICROBE AT A GLANCE

DISEASE IN DEPTH

1

A Brief History of Microbiology

Aquatic microorganisms, such as these, thrilled early microscopists with their beauty and antics.

LIFE AS WE KNOW IT WOULD NOT EXIST without microorganisms. Plants depend on microorganisms to help them obtain the nitrogen they need for survival. Animals such as cows and sheep need microbes in order to digest the carbohydrates in their plant-based diets. Ecosystems rely on microorganisms to enrich soil, degrade wastes, and support life. We use microorganisms to make wine and cheese and to develop vaccines and antibiotics. Through recombinant DNA technology (genetic engineering), we are now able to harness the power of these small microbes to do big jobs like mass producing important pharmaceuticals such as blood-clotting factor VIII and insulin for patients who desperately need them.

The human body is home to trillions of microorganisms, many of which help keep us healthy. Microorganisms are an essential part of our lives. Of course, some microorganisms do cause harm to us, from the common cold to more serious diseases such as tuberculosis, malaria, and AIDS. The threats of bioterrorism and new or re-emerging infectious diseases are real.

This textbook explores the roles—both beneficial and harmful—that microorganisms play in our lives, as well as their sophisticated structures and processes. This chapter will explore not only the history of microbiology, but how new discoveries have led to a number of new disciplines within the field of microbiology. We begin with the invention of crude microscopes that revealed, for the first time, the existence of this miraculous, miniature world.

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? What causes the spread of 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 close 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.

▲ **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 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?

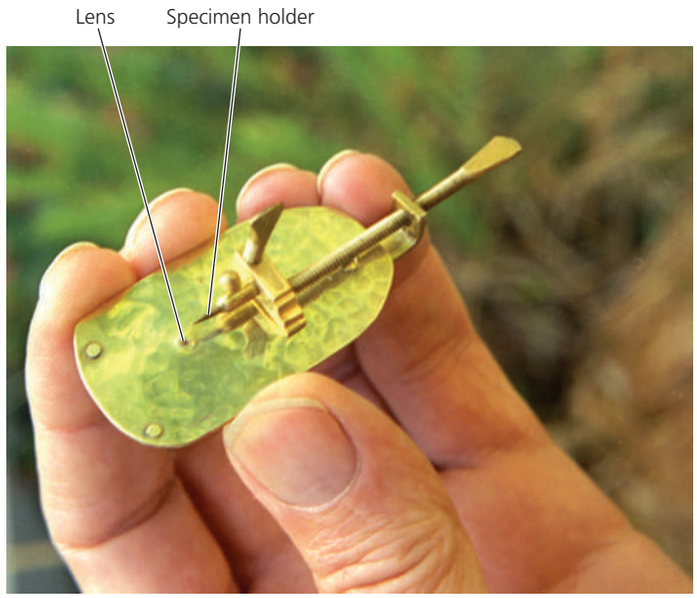
LEARNING OUTCOMES

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´věn-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 many 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 a magnifying lens, 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, 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, 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 metal



▲ **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.

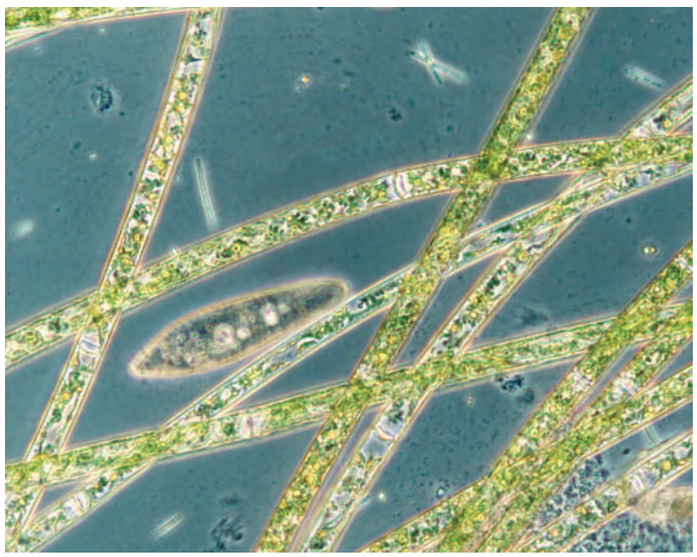
for a microscope from ore. Further, he often made a new microscope for each specimen, which remained mounted so that he could view it again and again. Then one day, he turned a lens onto a drop of water. We don't know what he expected to see, but certainly he saw more than he had anticipated. As he reported 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.[2]

Leeuwenhoek had discovered the 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. . . . 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.**



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

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 was one of the more famous scientists of his 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.)

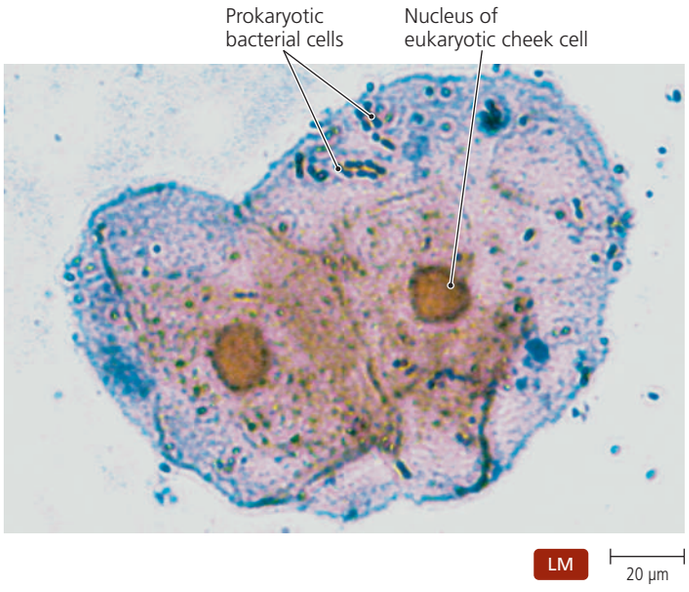
The microorganisms that Leeuwenhoek described can be grouped into six basic categories: bacteria, archaea, fungi, protozoa, algae, and small multicellular animals. The only types of microbes not described by Leeuwenhoek are *viruses*,[3] which are too small to be seen without an electron microscope. We briefly consider organisms in the first five categories in the following sections.

Bacteria and Archaea

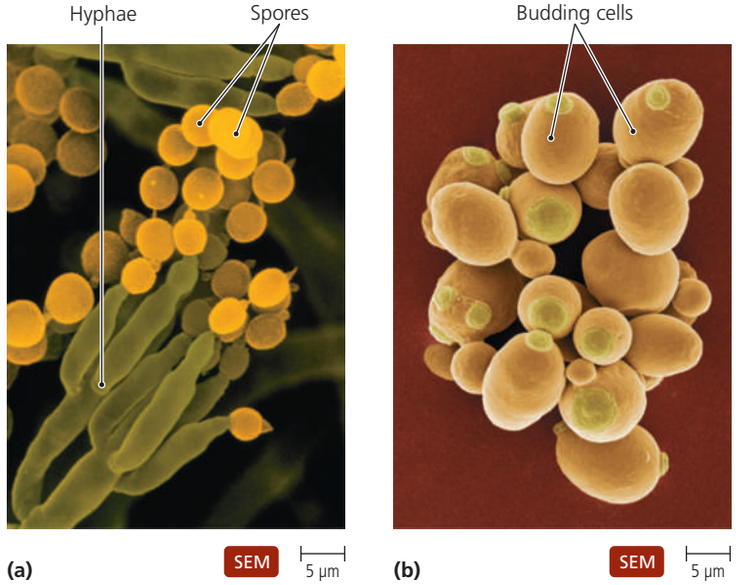
Bacteria and **archaea** are **prokaryotic,**[4] meaning that their cells lack nuclei; that is, their genes are not surrounded by a membrane. Bacterial cell walls are composed of a polysaccharide called *peptidoglycan,* though some bacteria lack cell walls. The cell walls of archaea lack peptidoglycan 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 19–21 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]Antony von Leeuwenhoek, in a letter to the Royal Society of London for the Promotion of Natural Knowledge.
[3]Technically, viruses are not "organisms," because they neither replicate themselves nor carry on the chemical reactions of living things.
[4]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, without beneficial bacteria, our bodies would be much more susceptible to disease. Also, 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.

Fungi

Fungi (fŭn´jī)[5] are **eukaryotic;**[6] that is, each of their cells contains a nucleus composed of genetic material surrounded by a distinct membrane. Fungi are different from plants because fungi 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). Another example of a yeast is *Candida albicans* (kan´did-ă al´bi-kanz), which causes most cases of yeast infections in women. (Chapters 12, 22, and 26 discuss fungi and their significance in the environment, in food production, and as agents of human disease.)

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*,[7] *cilia*,[8] or *flagella*.[9] 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* (plazmō´dē-ŭm), are nonmotile in their mature forms.

Many protozoa 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 23 further examine protozoa and some diseases they cause.)

[5]Plural of the Latin *fungus*, meaning "mushroom."
[6]From Greek *eu*, meaning "true," and *karyon*, meaning "kernel."
[7]Plural Greek *pseudes*, meaning "false," and *podos*, meaning "foot."
[8]Plural of the Latin *cilium*, meaning "eyelid."
[9]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)** *Blepharisma americana* moves by means of cilia. **(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[10] 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. Manufacturers use gelatinous chemicals from the cell walls of some large algae as thickeners and emulsifiers in many foods and cosmetics. Scientists use the algae-derived chemical called *agar* to solidify 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. (Chapter 12 discusses other aspects of the biology of algae.)

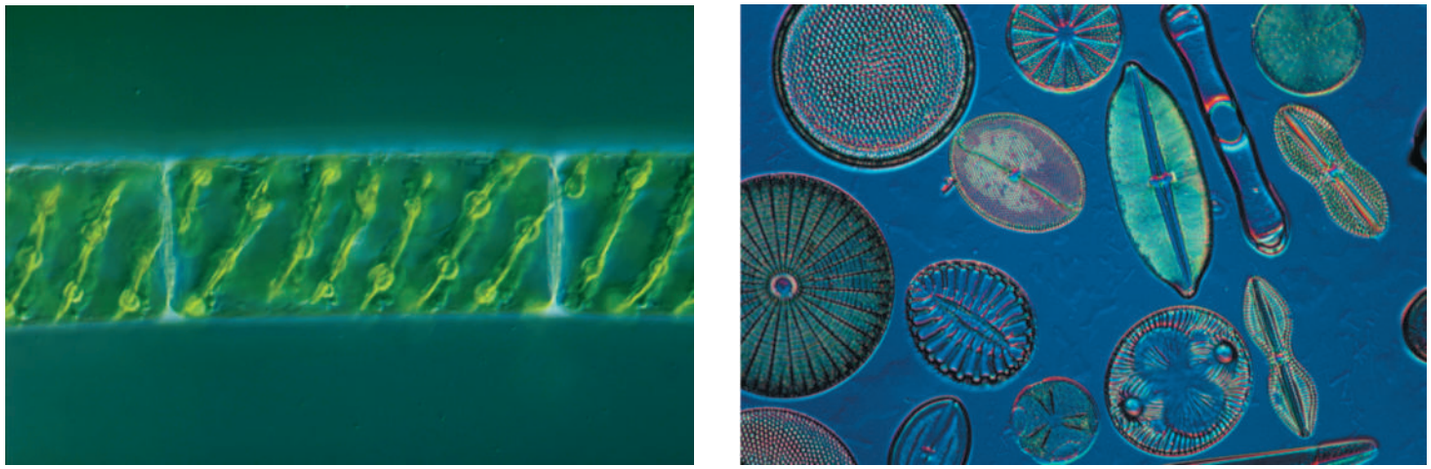
Other Organisms of Importance to Microbiologists

Microbiologists also study parasitic worms, which range in size from microscopic forms **(FIGURE 1.8)** to adult tapeworms over 10 meters (approximately 33 feet) in length. Even though most parasitic worms are not microscopic as adults, many of them cause diseases that were studied by early microbiologists, so microbiology books and classes often discuss parasitic worms. Further, laboratory scientists diagnose infections of parasitic worms by finding microscopic eggs and immature stages in blood, fecal, urine, and lymph specimens. (Chapter 23 discusses parasitic worms.)

The only type of microbe that remained hidden from Leeuwenhoek and other early microbiologists was the virus, which is typically much smaller than the smallest prokaryote and is not usually visible by light microscopy **(FIGURE 1.9)**. Viruses were not 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 24 and 25 discuss specific viral pathogens.)

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

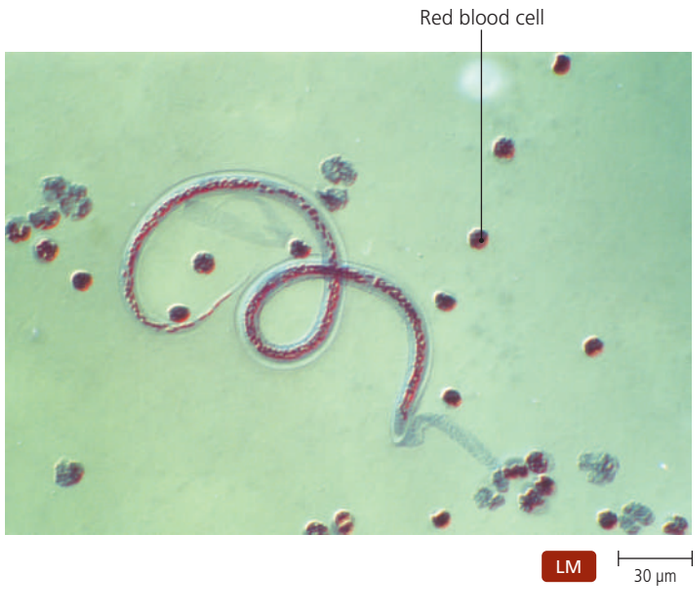
[10]Plural of the Latin *alga*, meaning "seaweed."



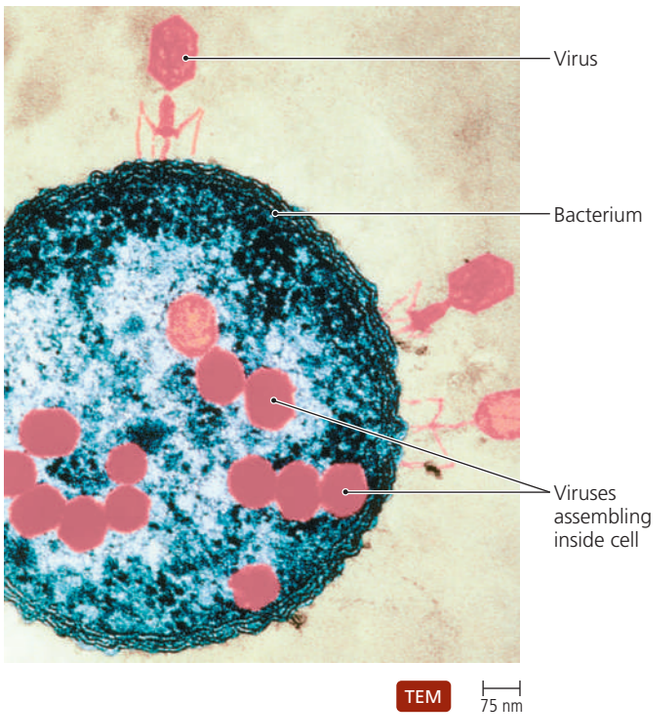
▲ **FIGURE 1.7 Algae. (a)** *Spirogyra.* These microscopic algae grow as chains of cells containing helical photosynthetic structures. **(b)** Diatoms. These beautiful algae have glasslike cell walls.

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 generally 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 scientific name, *Saccharomyces cerevisiae*, translates from Latin as "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—the first complete sequence published 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.

reproduction, through sexual reproduction, or from nonliving matter. The appearance of shrimp and toads in the mud of what so recently was a dry lake bed was seen as an example of the third process, which came to be known as *abiogenesis*,[11] or **spontaneous generation.** The theory of spontaneous generation as promulgated by Aristotle (384–322 B.C.) was widely accepted for over 2000 years because it seemed to explain a variety of commonly observed phenomena, such as the appearance of maggots on spoiling meat. However, the validity of the theory came under challenge in the 17th century.

Redi's Experiments

In the late 1600s, the Italian physician Francesco Redi (1626–1697) demonstrated by a series of experiments that when decaying meat was kept isolated from flies, maggots never developed, whereas meat exposed to flies was soon infested with maggots **(FIGURE 1.10)**. As a result of experiments such as these, scientists began to doubt Aristotle's theory and adopt the view that animals come only from other animals.

Needham's Experiments

The debate over spontaneous generation was rekindled when Leeuwenhoek discovered microbes and showed that they appeared after a few days in freshly collected rainwater. Though scientists agreed that larger animals could not arise spontaneously, they disagreed about Leeuwenhoek's "wee animalcules"; surely they did not have parents, did they? They must arise spontaneously.

▲ **FIGURE 1.10 Redi's experiments.** When the flask remained unsealed, maggots covered the meat within a few days. When the flask was sealed, flies were kept away, and no maggots appeared on the meat. When the flask opening was covered with gauze, flies were kept away, and no maggots appeared on the meat, although a few maggots appeared on top of the gauze.

The proponents of spontaneous generation pointed to the careful demonstrations of British investigator John T. Needham (1713–1781). He boiled beef gravy and infusions[12] of plant material in vials, which he then tightly sealed with corks. Some days later, Needham observed that the vials were cloudy, and examination revealed an abundance of "microscopical animals of most dimensions." As he explained it, there must be a "life force" that causes inanimate matter to spontaneously come to

[11]From Greek *a,* meaning "not"; *bios,* meaning "life"; and *genein,* meaning "to produce."

[12]Infusions are broths made by heating water containing plant or animal material.

HIGHLIGHT

Emerging and Reemerging Diseases: "The New Normal"

Middle East respiratory syndrome (MERS). West Nile encephalitis. Chikungunya. Ebola! These and diseases like them are emerging diseases—ones that have been diagnosed in a population for the first time or are rapidly increasing in incidence or geographic range. Among them are Middle East respiratory syndrome (MERS), a highly fatal, viral disease ostensibly acquired from camels and mosquito-born chikungunya, which causes severe joint pain. Indeed, unfamiliar diseases have become "the new normal" for health care workers, according to the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia.

Meanwhile, diseases once thought to be near eradication, such as measles, whooping cough, and tuberculosis, have reemerged in troubling outbreaks. Other near-vanquished pathogens such as smallpox or anthrax could become potential weapons in bioterrorist attacks.

How do emerging and reemerging diseases arise? Some are introduced to humans as we move into remote jungles and contact infected animals, some are carried by insects whose range is spreading as climate changes, and some take advantage of the AIDS crisis, infecting immunocompromised patients. In other cases, previously harmless microbes acquire new genes that allow them to be infective and cause disease. Some emerging pathogens spread with the speed of jet planes carrying infected people around the globe, and still others arise when previously treatable microbes develop resistance to our antibiotics.

MERS virus may be transmitted from camels to people.

However they arise, emerging and reemerging diseases that may develop into the next generation of high-profile infectious diseases are being monitored by scientists. Throughout this text, you will encounter many boxed discussions of such emerging and reemerging diseases.

life because he had heated the vials sufficiently to kill everything. Needham's experiments so impressed the Royal Society that they elected him a member.

Spallanzani's Experiments

Then, in 1799, the Italian Catholic priest and scientist Lazzaro Spallanzani (1729–1799) reported results that contradicted Needham's findings. Spallanzani boiled infusions for almost an hour and sealed the vials by melting their slender necks closed. His infusions remained clear unless he broke the seal and exposed the infusion to air, after which they became cloudy with microorganisms. He concluded three things:

- Needham either had failed to heat his vials sufficiently to kill all microbes or had not sealed them tightly enough.
- Microorganisms exist in the air and can contaminate experiments.
- Spontaneous generation of microorganisms does not occur; all living things arise from other living things.

Although Spallanzani's experiments would appear to have settled the controversy once and for all, it proved difficult to dethrone a theory that had held sway for 2000 years, especially when so notable a man as Aristotle had propounded it. One of the criticisms of Spallanzani's work was that his sealed vials did not allow enough air for organisms to thrive; another objection was that his prolonged heating destroyed the "life force." The debate continued until the French chemist Louis Pasteur **(FIGURE 1.11)** conducted experiments that finally laid the theory of spontaneous generation to rest.

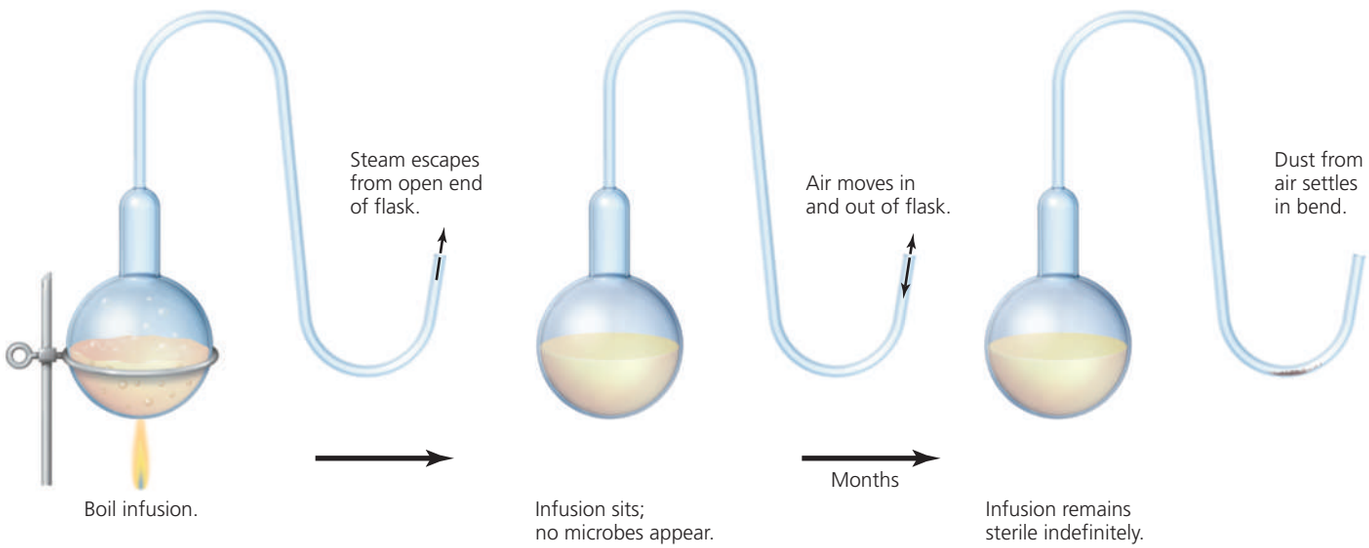
Pasteur's Experiments

Louis Pasteur (1822–1895) was an indefatigable worker who pushed himself as hard as he pushed others. As he wrote his sisters, "To *will* is a great thing dear sisters, for Action and Work usually follow Will, and almost always Work is accompanied by Success. These three things, Work, Will, Success, fill human existence. Will opens the door to success both brilliant and happy; Work passes these doors, and at the end of the journey Success comes to crown one's efforts." When his wife complained about his long hours in the laboratory, he replied, "I will lead you to fame."

▲ **FIGURE 1.11 Louis Pasteur.** Often called the Father of Microbiology, he disproved spontaneous generation. In this depiction, Pasteur examines some bacterial cultures.

Pasteur's determination and hard work are apparent in his investigations of spontaneous generation. Like Spallanzani, he boiled infusions long enough to kill everything. But instead of sealing the flasks, he bent their necks into an S-shape, which allowed air to enter while preventing the introduction of dust and microbes into the broth **(FIGURE 1.12)**.

Crowded for space and lacking funds, he improvised an incubator in the opening under a staircase. Day after day, he



▲ **FIGURE 1.12 Pasteur's experiments with "swan-necked flasks."** As long as the flask remained upright, no microbial growth appeared in the infusion.