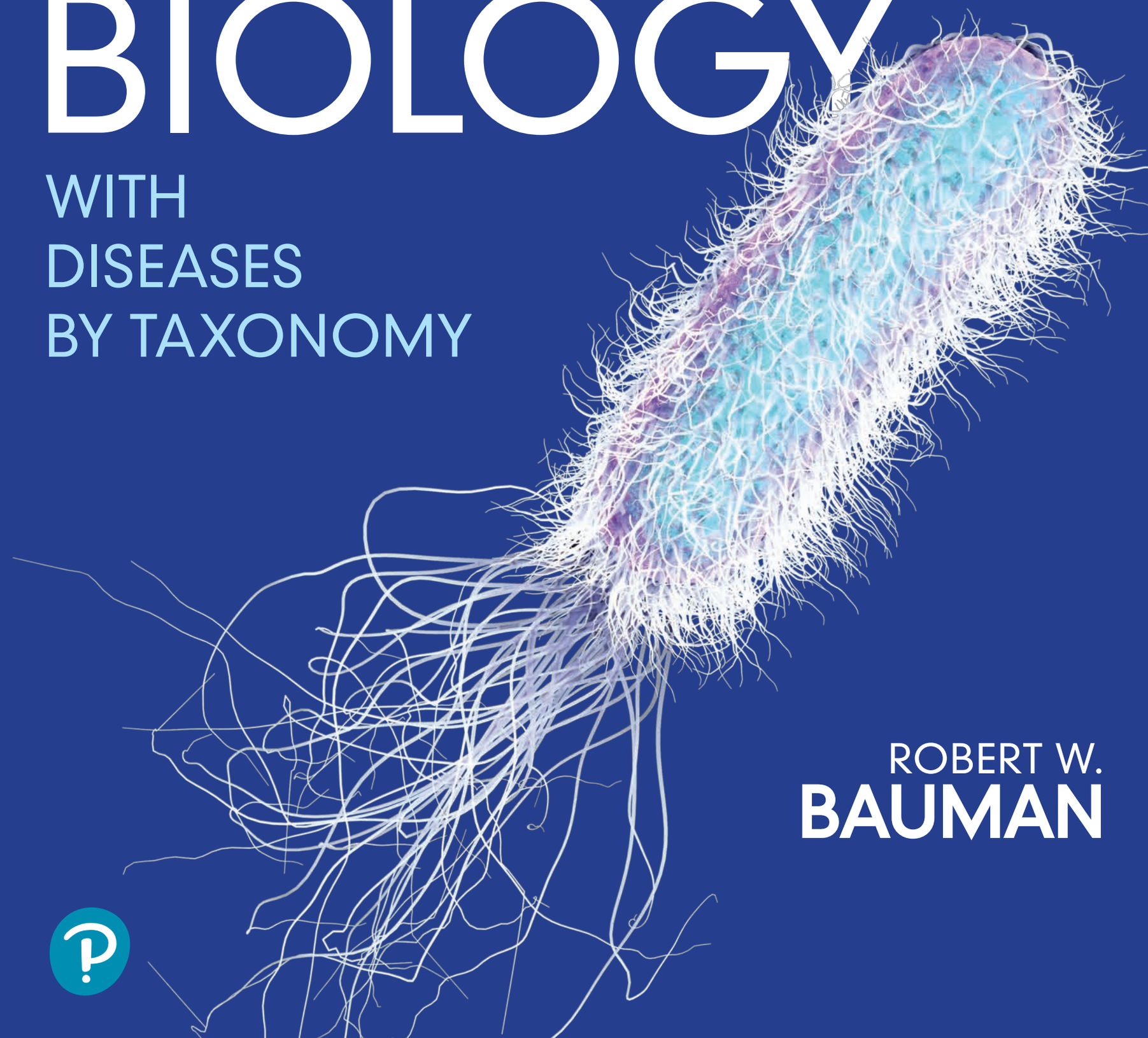
SIXTH EDITION

MICRO BIOLOGY

WITH DISEASES BY TAXONOMY



ROBERT W. BAUMAN

SIXTH EDITION

MICRO BIOLOGY

WITH DISEASES BY TAXONOMY

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Michelle, you are my best friend, my closest confidant, my cheerleader, my partner, my love for over thirty-five years. Thank you for working alongside me to bring this book to fruition. I love you more now than then.

—Robert

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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 for over 30 years. In 2004, the students of Amarillo College selected Dr. Bauman as the recipient of the John F. Mead Faculty Excellence Award. He is gratified to have been nominated by the students every year since then, though College policy currently allows a teacher to win only once. He received an M.A. degree in botany and oceanography from the University of Texas at Austin and a Ph.D. in biology from Stanford University. His research interests have included the morphology, ecology, and culturing of freshwater algae and photosynthetic protozoa, the cell biology of marine algae (particularly the deposition of cell walls and intercellular communication), environmentally triggered chromogenesis in butterflies, and remediation of terrestrial oil pollution 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 a professor of pre-nursing and general microbiology at Sam Houston State University and is Director of the Professional and Academic Center for Excellence, which focuses on improving pedagogy. In 2010, he was Distinguished Alumnus of the Graduate School of Biomedical Sciences of Baylor College of Medicine, where he earned his Ph.D. in biochemistry. He is active in ASM and received the Texas Branch 2015 Faculty Teaching Award. He was chair of the 2013 ASM Conference for Undergraduate Educators and currently serves on the editorial board for the Journal of Microbiology & Biology Education. He is also an affiliate staff member with the international organization Cru. He loves mentoring students and spending time with his wife of 25 years and their five children.

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PREFACE

The re-emergence of measles, an historical epidemic of Ebola hemorrhagic fever, and the emergence of Zika virus infections, spotted fever rickettsioses, Middle East respiratory syndrome, and other diseases; cases of strep throat, MRSA, and tuberculosis; the progress of research into more effective and new vaccines, advance in microbial genetics, including genetic engineering and gene therapy; 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 explored microbiology with undergraduates for over 30 years and witnessed firsthand how students struggle with the same topics and concepts year after year. My students begged me to write this book to address these challenging topics. 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 sixth 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 many terrific suggestions received from colleagues and students alike. The feedback from instructors who adopted previous editions has been immensely gratifying and is much appreciated. Seven new Solve the Problem! features use problem-based learning, encouraging students to put knowledge into practice. New case studies were developed to open each chapter to engage students with real world, practical problems in clinical microbiology. Further, responding to recent pedagogical research that shows that learning occurs more readily with frequent opportunities to review and apply information, Micro Check questions were added throughout every chapter. Micro Checks are short questions that encourage students to focus attention on the Learning Outcomes, increase their learning, and enhance metacognition—awareness of student's own learning. Diligent application of Micro Checks will increase student success.

In this new edition:

- NEW Before You Begin questions refresh students' critical chemistry and general biology knowledge from pre-requisite courses and previous chapters for success in the course. Before You Begin questions appear in the chapter openers and can be assigned in Mastering Microbiology. In Mastering, the Before You Begin questions are interactive and provide wrong and correct answer feedback with embedded hints that provide just-in-time remediation via tutorials that fill in students' individual skill gaps.
- NEW Solve the Problem features carry education to a new level with problem-based learning exercises that excite, inspire, and stimulate students to apply critical thinking skills to current microbiological quandaries. Each of the seven Solve the Problem features challenges students to work together to devise and articulate possible resolutions to a timely, real world problem. Solve the Problem exercises can stand alone or be expanded with ambitious extensions and resources available in Mastering Microbiology®.
- NEW MicroChecks provide an intuitive check in for students to ensure mastery of the new chapter content. These formative assessments appear in the text and can be assigned in Mastering Microbiology. In Mastering, the interactive questions provide immediate feedback for just-in-time remediation, directing students to videos and animations that reinforce the concepts.
- Micro Matters features tie together subjects from different chapters to encourage students to apply and synthesize new knowledge as they explore medical cases and answer pertinent questions. Each of the five Micro Matters video tutorials is paired with assessments in Mastering Microbiology®.
- The genetics and immunology chapters (Chapters 7, 8, 15, and 16) have been reviewed and revised by specialists. These now reflect the most current understanding of these rapidly evolving fields, including new discussions of next-generation DNA sequencing and of CRISPR.
- Nearly 300 NEW and revised micrographs, photos, and figures enhance student understanding of the text and boxed features.
  - NEW Chapter 27 is dedicated to microbial ecology and microbiomes.
- NEW AND EXPANDED MasteringMicrobiology® includes:
  - NEW Concept Maps give students the opportunity to construct their knowledge using a list of key terms as higher level Bloom's activities in a scaffolded, drag and drop format. The interactive end-of-chapter activities can be assigned in Mastering Microbiology, providing students with immediate feedback for just-in-time remediation that directs them to specific content to reinforce the concepts.
  - NEW Interactive Microbiology Modules, 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. New modules include Antimicrobial Resistance, Aerobic Resistance, and the Human Microbiome.
- Micro Matters case tutorials and assessments connect chapter concepts and coach students through applying and synthesizing new knowledge.
- MicroBoosters pair video tutorials and assessments covering key concepts that students often need to review, including Basic Chemistry, Cell Biology, Biology and more!
- The Microbiology 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 ensure students come prepared for lab time.
- Lab Practical and post-lab quizzes reinforce what students have learned.

Mastering Microbiology® also provides access to Dynamic Study Modules to help students 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. Additionally, Mastering Microbiology® includes Learning Catalytics—a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics, instructors can assess students in real time using open-ended tasks to probe student understanding using Pearson's library of questions or designing their own.

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

CHAPTER-BY-CHAPTER REVISIONS

- More closely aligned assessment questions with Learning Outcomes
- Every chapter now begins and ends with **Micro in the Clinic**—a clinical case study covering a disease relevant to the chapter
- Every chapter opener contains **Before You Begin** questions to spur students to test their foundational knowledge before beginning the chapter
- New **Micro Check** questions throughout every chapter challenge students to use newly acquired knowledge as they proceed
- Clinical consultants evaluated, rewrote, and improved each case study to be more medically relevant and accurate

1 A Brief History of Microbiology

- New case study opens the chapter
- Eight other new photos (1.2, 1.3, 1.11, 1.15, 1.16, 1.17, 1.20, 1.22)
- Two figures revised for better pedagogy, clarity, and accuracy (1.10, 1.21)
- Updated map showing countries having transmission of variant Creutzfeldt-Jakob disease (vJCD)
- New **Solve the Problem: Smallpox: To Be or Not to Be?** problem-based learning exercise concerning complete smallpox virus destruction
- Simplified the language and sentence structure
- Added discussion of the contribution of Fanny Hesse to the success of Koch's laboratory with her introduction of agar
- Increased coverage of Florence Nightingale and her accomplishments
- Added the work of Lady Mary Worley Montague to the discussion of the development of vaccination
- Introduced the success of gene therapy to treat several inherited immune deficiencies
- Added to list of current problems in microbiology: Ebola control and the problems associated with emerging diseases
- Added a Tell Me Why concerning the accomplishments of Nightingale leading to consideration of her as Mother of Medical Microbiology
- Added a critical thinking question concerning the "fatherhood" of microbiology (Leeuwenhoek vs. Pasteur)
- Deleted Learning Outcome 1.21 concerning fastest-growing fields within microbiology; this topic is better covered by an instructor in class rather than in a textbook

2 The Chemistry of Microbiology

- New case study opens the chapter
- Representation of ether bond in Table 2.3 clarified for better pedagogy
- Clarified that most organisms code for 21 amino acids, though 20 are more common
- New Learning Outcome regarding *electron shells* and *valence electrons*
- Added Learning Outcomes 2.3 regarding the chemistry of carbohydrates and Learning Outcome 2.25 regarding the general structure of amino acids

3 Cell Structure and Function

- New case study opens the chapter
- Seven other new/upgraded photos (3.1b, 3.7b & c, 3.11, 3.24, 3.25b, 3.37)
- Revised and enhanced artwork in eleven figures for enhanced pedagogy (3.2, 3.3, 3.15, 3.16, 3.21, 3.22, 3.23, 3.32, 3.33, 3.37, 3.39)
- Enhanced discussion of chemistry and function of lipids in archaeal cytoplasmic membranes
- Clarified that *endotoxin* refers to lipopolysaccharide (LPS), which contains the toxic molecule lipid A
- Recognized Lynn Margulis as a proponent of the theory of endosymbiosis
- Added **Clinical Case Study: The Big Game** about strep throat

4 Microscopy, Staining, and Classification

- New case study opens the chapter
- Five other new/upgraded photos (4.10c, 4.11c, 4.12, 4.18, 4.24)
- Revised and enhanced artwork in Figure 4.4 for enhanced pedagogy
- Expanded discussion of resolution; immersion oil; the appearance of scanning electron, scanning tunneling, and atomic force micrographs; mordants; definitions of microbial species and serotypes; and the role of George Fox in the discovery of the archaea and three domains of life
- Added contribution of Rebecca Lancefield to serological identification of streptococci
- Added discussion of matrix-assisted laser desorption/ionization time-of-flight (MALDI/TOF) mass spectrometry as a method of identification of microbial species and diagnoses
- At request of reviewers and instructors, reduced complexity and chapter length by removing detailed figures for dark field, phase, and scanning electron microscopy

5 Microbial Metabolism

- New case study opens the chapter
- One new photo (5.23b)
- Revised fifteen figures for greater clarity and better pedagogy (5.3, 5.6, 5.9, 5.10, 5.11, 5.12, 5.14, 5.15, 5.17, 5.18, 5.21, 5.22, 5.25, 5.31, Concept map)
- Revised textual explanation of glycolysis to make it more clear and pedagogically efficient
- Fully adopted current name *citric acid cycle* instead of eponymous *Krebs cycle*

6 Microbial Nutrition and Growth

- New case study opens the chapter
- New **Solve the Problem: The Microbes Ate My Homework** problem-based learning exercise concerning using engineered microbes to reduce cardboard waste
- Revised five figures for greater clarity and better pedagogy (6.2, 6.6, 6.10, 6.21, 6.23)
- One new figure on quorum sensing (6.7)
- Two new photos (6.10b, 6.24)
- Revised Learning Outcome 6.8 to be more specific (Describe methods for collecting clinical specimens from the skin, blood, cerebrospinal fluid, stomach, urine, lungs, and diseased tissue.)
- Expanded discussion of singlet oxygen and superoxide radicals as oxidizing agents, the nature of extracellular matrix in biofilms, and quorum sensing
- Clarified the method of counting microbes using a cell counter

7 Microbial Genetics

- New case study opens the chapter
- Upgraded twenty-three figures for greater clarity, accuracy, ease of reading, and better pedagogy (7.1, 7.3, 7.5, 7.6, 7.8, 7.9, 7.10, 7.11, 7.12, 7.13, 7.15, 7.16, 7.17, 7.18, 7.19, 7.20, 7.21, 7.25, 7.26, 7.27, 7.28, 7.29, 7.33)
- One new figure concerning termination of translation (7.20)
- Added new Learning Outcome (7.7) concerning the concept that nucleotide base complementarity ensures precise and accurate DNA replication
- Added critical thinking question to Figure 7.13 concerning central dogma of genetics
- Noted some contributions of Esther Lederberg to microbial genetics (development of replica plating and the discovery of the F plasmid)
- Clarified the structure of eukaryotic chromosomes
- Added term *constitutive genes* to contrast with operon genes
- Moved **Beneficial Microbes: Life in a Hot Tub (Taq polymerase)** to chapter 8 where its direct application for PCR is more apparent
- Moved **Emerging Disease Case Study: *Vibrio vulnificus* Infection** to chapter 6: the microbe's use of quorum sensing increases its virulence

8 Recombinant DNA Technology

- New case study opens the chapter
- Modified two figures for better pedagogy (8.7, 8.8)
- One new figure illustrating a form of CRISPR (8.4)
- Added seven NEW Learning Outcomes concerning CRISPR, uses of synthetic nucleic acids, PCR, fluorescent *in situ* hybridization (FISH), functional genomics, Sanger sequencing, and next generation sequencing
- Deleted figures for Southern blots and Sanger automated DNA sequencing as these techniques are more historical than current
- Enhanced or added discussion of restriction enzymes *Hae*III and *Msp*I; CRISPR-Cas; real-time PCR (RT-PCR); Sanger sequencing methods; next generation DNA sequencing (NGS), including pyrosequencing and fluorescent methods; functional genomics; microbiomes; transcriptomics, metabolomics, biomedical animal models; heat shocking for the uptake of DNA; and successful gene therapies
- Moved **Beneficial Microbes: Life in a Hot Tub (Taq polymerase)** from chapter 7 to chapter 8 where its direct application for PCR is more apparent
- Fully adopted current name *recombinant DNA technology* instead of the sometimes controversial or problematic *genetic engineering*
- Added two end of chapter questions over CRISPR

9 Controlling Microbial Growth in the Environment

- New case study opens the chapter
- Revised one figure for better accuracy, currency, and pedagogy (9.11)
- Two new photos (9.4, 9.11)
- New **Solve the Problem: How Clean is Too Clean** problem-based learning investigation concerning the potential overuse of household and industrial disinfectants
- Revised definition of heavy-metal ions
- Updated techniques for deactivation of prions, coverage of thimerosal in vaccines, and activity of AOAC International in developing disinfection standards

10 Controlling Microbial Growth in the Body: Antimicrobial Drugs

- New case study opens the chapter
- Updated and revised tables of antimicrobials to include all new antimicrobials mentioned in disease chapters, including antibacterial capreomycin, antihelmintic bithionol, anti-influenzavirus peramivir; updated sources of drugs, modes of action, clinical considerations, and methods of resistance
- Eight revised figures for greater clarity, accuracy, ease of reading, and better pedagogy (10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.16; map of worldwide, community-associated MRSA
- One new figure showing Therapeutic index (10.15)
- Two new photos (10.10, 10.14)
- Added discussion of: 1) drugs that inhibit protein synthesis by interfering with the charging of tRNA molecules, the new antibiotic teixobactin, 2) the importance of persister cells for antimicrobial resistance, 3) the CDC's threat levels for microbial drug resistance
- Enhanced and clarified discussion of therapeutic index, therapeutic window, and adverse effects of gramicidin
- Added Learning Outcome over persister cells
- Increased discussion of women's contributions to development of antimicrobial drugs: developing the first effective antiviral agent (acyclovir), the first anti-HIV agent (azidothymidine), and an antifungal agent (nystatin); elucidation of the 3-D structure of penicillin, which allowed the synthesis of synthetic penicillins; and as leaders of medical organizations, director-general of WHO and director of the CDC
- Removed amantadine as a treatment for influenza A
- Added new Learning Outcome on action of mupirocin, which interferes with charging of $tRNA^{Ile}$

11 Characterizing and Classifying Prokaryotes

- New case study opens the chapter
- Added four **Tell Me Why** critical thinking questions to text
- Three revised figures for better pedagogy (11.6, 11.10, 11.24)
- Two new photos (11.14b, 11.18)
- Clarified binary fission of cocci to form tetrads; clarified taxonomic groupings among the bacteria, expanded on the properties mycoplasmas use to protect themselves from osmosis; distinguished between true reproductive spores and endospores; expanded coverage of acid-fast staining and acid-fast bacilli (AFBs); expanded on the zetaproteobacteria
- New Learning Outcomes concerning: classes of proteobacteria, the use of *Agrobacterium* in genetic modification of plants
- New end-of-chapter Short Answer Question concering the special features of snapping division

12 Characterizing and Classifying Eukaryotes

- New case study opens the chapter
- Eight new photos (12.7, 12.13, 12.16b, 12.20b, 12.21a(2), 12.25, **Emerging Disease Case Study: Chronic Aspergillosis**)
- Four revised artwork for better pedagogy (12.1, 12.2, 12.8, 12.18)
- Updated, revised, or clarified discussion of cytokinesis; asexual spores of fungi; truffles; expanded discussion and location of algal flagella
- New Learning Outcomes concerning fungal nutrition and fungal morphology

13 Characterizing and Classifying Viruses, Viroids, and Prions

- New case study opens the chapter
- New **Solve the Problem: Microengineer a Better Mosquito?** problem-based learning exercise concerning using genetically engineered *Wolbachia* bacteria to reduce mosquito populations
- Updated viral nomenclature to correspond to changes approved by the International Committee on Taxonomy of Viruses (ICTV) (2016)

- Six new photos (13.3b, 13.5a, 13.7b, **Beneficial Microbes: Prescription Viruses?**, 13.19, 13.21)
- Upgraded three figures for better pedagogy and currency (13.22, 13.23, 13.24)
- Added discussion of the work of Esther Lederberg in the discovery of lambda phage and lysogeny
- Revised discussion of prions; expanded discussion of bacteriophages for treatment of human diseases and synthesis strategies of animal viruses

14 Infection, Infectious Diseases, and Epidemiology

- New case study opens the chapter
- New **Solve the Problem: Microbes in the Produce Aisle** problem-based learning exercise concerning epidemiological case study concerning *Legionella* outbreak
- Epidemiology charts, tables, graphs, and maps updated
- Updated list of nationally notifiable infectious conditions (changed AIDS to HIV Stage III; added cancer, carbapenems-resistant infections of Enterobacteriaceae; Zika virus disease and infections; changed SARS to severe acute respiratory syndrome-associated coronavirus disease)
- Changed four figures for better pedagogy, timeliness, or clarity (14.7, 14.14, 14.16, 14.18)
- One new photo (14.12)
- Changed the term *normal microbiota* to *resident microbiome* (*resident microbiota*) to reflect current vocabulary
- Clarified the fact that microbiota normal for one person may be different in another
- New question for **Clinical Case Study: A Deadly Carrier** concerning control of an epidemic when antimicrobial drugs are unavailable
- Clarified and expanded discussion of parenteral infections and the list of arthropod vectors for microbial diseases

15 Innate Immunity

- New case study opens the chapter
- Added new **Tell Me Why** critical thinking questions to **The Body's First Line of Defense** concerning lysozyme
- Expanded coverage of the action of antimicrobial peptides (defensins), probiotics, defensive action of resident microbiome, and phagocytosis
- Clarified the processes involved in the first line of defense
- Added nature and action of dermicidins, fatty acids, and mucins
- Modified one figure for enhanced clarity and better pedagogy (15.8)
- Three new photos [15.5 (2), 15.10]

16 Specific Defense: Adaptive Immunity

- New case study opens the chapter
- Five revised figures for greater accuracy and pedagogical efficiency (16.3, 16.4, 16.7, 16.9, 16.12, 16.14)
- One new photo (16.5)
- Revised and added to Learning Outcomes (16.27), concerning the events in antibody immune responses
- New table (16.1) summarizing differences between innate and adaptive immunity
- Revised and clarified terminology for CD8+ and CD4+ cells, genetic basis for creation of BCR and TCR diversity, binding capability of MHC

17 Immunization and Immune Testing

- New case study opens the chapter
- New **Solve the Problem: Rights versus Responsibilities** problem-based learning exercise concerning balancing the benefits of immunization versus the rights of families to direct their own health care
- Added a **Tell Me Why** critical thinking question to text
- Updated to newly revised CDC 2018 vaccination schedule for children, adolescents, and adults
- Updated table of vaccine preventable diseases in USA
- Three revised figures for better pedagogy (17.1, 17.2, 17.3)
- Two new photos (17.10, 17.11b)
- Updated, clarified, and in some cases, increased coverage of safety and efficacy of immunizations, treatment with passive immunotherapy using monoclonal antibodies, determination of blood type by agglutination, use of indirect fluorescent immunoassays, antibody sandwich ELISA, and immunochromatographic assays
- Standardized usage of *immunization* versus *vaccination*, which specifically describes immunization against smallpox
- Reworded labeled antibody tests as labeled immunoassays

18 Hypersensitivities, Autoimmune Diseases, and Immune Deficiencies

- New case study opens the chapter
- Three revised figures for better pedagogy, accuracy, and clarity (18.1, 18.5, 18.6)
- Updated and clarified the role of IgE, basophils, and mast cells in type I hypersensitivity

19 Pathogenic Gram-Positive Bacteria

- New case study opens the chapter
- Updated diagnoses, incidence data, treatments, and prevention, particularly for necrotizing fasciitis, streptococcal pneumonia, tetanus, tuberculosis
- Seven new photos (19.2, 19.7, 19.11, 19.18, 19.19, 19.21, **Microbe at a Glance: *Streptococcus* pneumoniae**
- Six revisions to figures for consistency, currency, accuracy, and better pedagogy [19.5, 19.13, **Disease in Depth: Tuberculosis** (2), **Listeriosis** (2)]
- Added discussion of cellulitis, HA-MRSA, CA-MRSA, use of term *GAS* for group A *Streptococcus* (*S. pyogenes*), red squirrels as host for *Mycobacterium leprae*
- Updated and clarified discussion of erysipelas, rheumatic fever, puerperal fever, necrotizing fasciitis (it is polymicrobial rather than monomicrobial), Lancefield classification of *Enterococcus*, atypical (walking) pneumonia
- Updated immunization schedule for diphtheria
- Enhanced Concept Mapping to include new treatment regimen for tuberculosis
- New **Clinical Case Study** over MRSA cellulitis

20 Pathogenic Gram-Negative Cocci and Bacilli

- New case study opens the chapter
- New Learning Outcome regarding antibody immune responses
- Updated all diagnoses, treatments, and incidence data
- Twelve new photos (20.2, 20.4a, 20.7b, 20.12, **Disease in Depth: Urinary Tract Infections** (2), 20.13, 20.20, 20.21, 20.25, 20.28, 20.29)
- Fourteen revised figures for better pedagogy (20.3, 20.7a, 20.8, 20.9, 20.10, **Disease in Depth: Urinary Tract Infections** (3); 20.15, 20.16, 20.17, 20.22, 20.23, 20.25)
- Added discussion of strains of *E.* coli, carbapenem-resistant enterobacteriaceae (CREs); Margaret Pittman's role in elucidating the strains of *H. influenzae*; emergence of extremely drug resistant (XDR) *Salmonella typhi* in Pakistan in 2018
- Updated and clarified discussion of breakdown of maltose by *Neisseria*

21 Rickettsias, Chlamydias, Spirochetes, and Vibrios

- New case study opens the chapter
- Updated all diagnoses, treatments, and incidence data
- Four new photos [21.5, 21.9(a-c)]
- Eight revised figures for better pedagogy (21.1, 21.2, **Disease in Depth: Rocky Mountain Spotted Fever** (1), 21.3, **Microbe at a Glance: *Treponema***, 21.8, 21.12, 21.13)
- Added discussion of potential vaccine against *Chlamydia trachomatis*, manifestations of *Chlamydia trachomatis*, and a new vaccine against Lyme disease

22 Pathogenic Fungi

- New case study opens the chapter
- New Learning Outcome concerning microsporidia and microsporidioses
- Updated all diagnoses, treatments, and incidence data, particularly histoplasmosis, blastomycosis, and coccidioidomycosis
- Updated name of *Penicillium marneffei* to *Talaromyces marneffei* (renamed in 2015)
- Modified six Questions for Review at the end of the chapter (MC: 4, 13; MTF: 3, 10; FIB: 7; SA: 4)
- Modified Concept Mapping for the up to date treatment for aspergillosis (vericonazole)
- Modified five figures for enhanced pedagogy and lucidity (22.2, 22.3, 22.5, 22.7, **Disease in Depth: Candidiasis**)
- One new figure concerning microsporidial life cycle (22.14)
- Four new photos for enhanced pedagogy (22.4b, 22.9, 22.11, 22.20)
- Updated and enhanced discussion of potential vaccines against fungi
- Added discussion of emerging pathogens—microsporidia

23 Parasitic Protozoa, Helminths, and Arthropod Vectors

- New case study opens the chapter
- Updated all diagnoses, incidence data, and treatments, particularly giardiasis, schistosomiasis, and babesiosis
- Ten new, more engaging photos (23.2, 23.6, 23.8, **Disease in Depth: Giardiasis** (1), 23.10, 23.12, 23.15, 23.18b, 23.19b and c)
- Fourteen revised, updated, enhanced, and pedagogically more effective figures [23.1, 23.3, 23.5, 23.6, **Disease in Depth: Giardiasis** (3), **Disease in Depth: Malaria** (4), 23.9, 23.14, **Emerging Disease Case Study: Babesiosis**]
- Clarified features of the life cycles of trypanosomes, nematodes
- Redrew Concept Mapping to more accurately reflect parasitic protozoa

24 Pathogenic DNA Viruses

- New case study opens the chapter
- Updated all diagnoses, incidence data, and treatments, adenoviral diseases, hepatitis B, and newly-approved treatment for smallpox
- Three new photos (24.3, 24.7, 24.15)
- Eight revised, updated, enhanced, and pedagogically more effective figures [**Microbe at a Glance: *Orthopoxvirus variola*** (Smallpox Virus (1)), 24.12, **Disease in Depth: Papillomas** (2), 24.16, **Microbe at a Glance: *Adenovirus***, 24.18, 24.20, 24.21
- Updated and enhanced discussion of adenoviral diseases, the role of papillomaviruses in the development of oral and throat cancers, and sign of erythema infectiosum

25 Pathogenic RNA Viruses

- New case study opens the chapter
- Updated all diagnoses, treatments, incidence data, and case studies, particularly hepatitis C, West Nile virus encephalitis, dengue and dengue hemorrhagic fever, SARS and MERS, HIV/AIDS, measles, Ebola hemorrhagic fever, rotavirus diarrhea
- Added new diseases: Zika fever and Zika congenital syndrome
- New Learning Outcome concerning Zika virus and its diseases
- Replaced **Emerging Disease Case Study: H5N1 Influenza** with new **Emerging Disease Case Study: A Deadly Mosquito Bite?**, concerning Zika virus, Zika fever, and Zika congential syndrome
- Twenty figures revised, updated, or enhanced for better pedagogy [25.2, 25.9, 25.10, 25.11, 25.12, 25.14, 25.18, 25.20, 25.22, 25.24, 25.27, **Microbe at a Glance: *Morbillivirus measles virus*** (1), 25.29, 25.30, 25.32, **Disease in Depth: Ebola** (3), 25.37]; Concept Mapping: Hepatitis
- Twelve new photos [25.6, 25.7, 25.9, **Beneficial Microbe: Eliminating *Aedes*-Borne Diseases?** (1), **Emerging Disease Case Study: A Deadly Mosquito Bite?** (1), 25.16, **Microbe at a Glance: *Morbillivirus measles virus*** (1), 25.33, **Disease in Depth: Ebola (3), Clinical Case Study: A Case of AIDS** (1)]
- Increased discussion of encephalitis arboviruses, coxsackievirus B, hepatitis E, dengue fever and dengue hemorrhagic fever, rubella, measles, hemorrhagic fevers, and Zika virus disease

26 Applied and Industrial Microbiology

- Split the chapter into two so as to give more attention to applied microbiology
- New chapter opener case study and photo
- One new photo (26.14)
- Five figures revised, updated, or enhanced for better pedagogy (26.1, **Emerging Disease: Primary Amebic Meningoencephalitis**, 26.6, 26.8, 26.9, 26.10)
- Revised and enhanced discussion of pickling, "live" yogurt, rennin, cheese making, butanol as an alternative fuel, seaweed as biosensors, drinking water treatment, wastewater treatment
- Added four fill-in-the-blank questions and two new Visualize It! questions to the Questions for Review at the end of chapter

27 Microbial Ecology and Microbiomes

- Split the chapter from Chapter 26 so as to give more attention to the worldwide microbiome as well as ecology of the human body and its microbiome
- New case study opens the chapter
- New **Solve the Problem: Fecal Microbiome Transfer: Medicine of Magic?** problem-based learning exercise on ecology of human microbiome and the use of fecal transplantation to treat chronic gastrointestinal diseases
- Four figures revised, updated, or enhanced for better pedagogy (27.1, 27.4, 27.5, 27.6)
- One other new photo (27.7)
- New **Clinical Case Study: Bioterrorism in the Mail** concerning anthrax
- Added coverage of the World Microbiome Project
- One new Multiple Choice question, one new Modified True/False question, one new Fill in the Blanks question, and three new Critical Thinking questions added to the end of chapter Questions for Review

REVIEWERS FOR THE SIXTH EDITION

"Thank you!" to 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 sixth edition, I especially extend my deepest appreciation to the following reviewers.

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I am grateful to Wendy Mears, Allison Rona, and Kelly Galli in Marketing. They have led the amazing Pearson sales representatives to do a terrific job of keeping in touch with the professors and students who provide so many wonderful suggestions for this textbook. As always, I am humbled, inspired, and encouraged by all the sales representatives; your role on the team deserves more gratitude than I can express here or with grapefruit.

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Robert W. Bauman
Amarillo, Texas

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MICROBE AT A GLANCE

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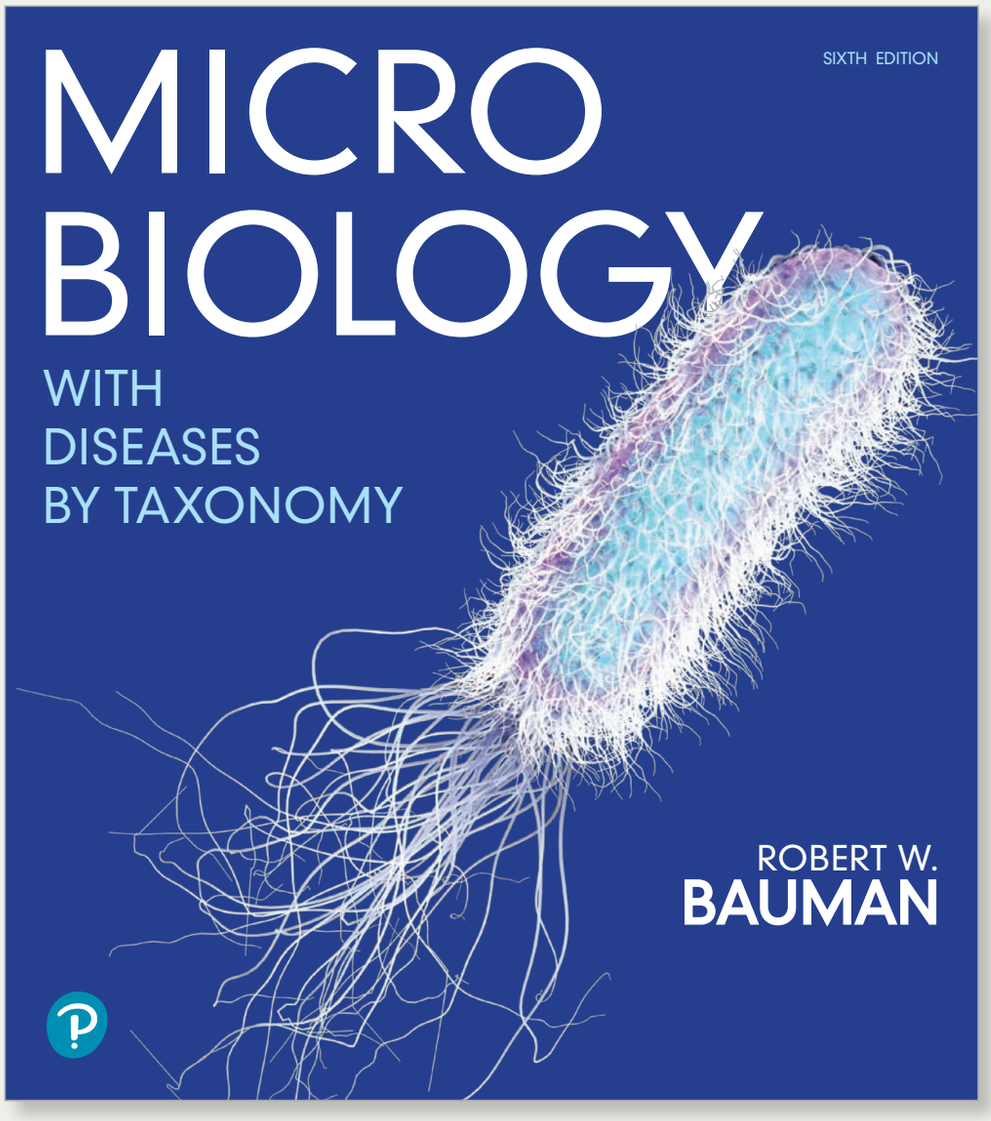
Explore the Invisible World of Microbiology and Why it Matters to Human Life

***Microbiology With Diseases by Taxonomy,* Sixth Edition** encourages a deep understanding of why microbiology matters to health as well as disease. Just-in-time remediation and checkpoints throughout the eText help students to progress in their understanding of course concepts. Students expand their learning in Mastering Microbiology with Interactive Microbiology case studies which give students the opportunity to practice making predictions and observing outcomes. The Sixth Edition also includes discussions about emerging research on recombinant DNA and CRISPR.



Pearson

Maximize Learning with Effective Study Tools

Before You Begin

1. Which cellular structure is present in eukaryotes and not in prokaryotes?
2. Which of the following organisms are classified as eukaryotes: archaea, bacteria, fungi, helminths, and protozoa?
3. What are the differences between the structure of DNA in eukaryotic nuclei and that in bacteria?
4. What organelle generates most of the energy in eukaryotic cells?
5. What is the difference between eukaryotic and prokaryotic flagella?

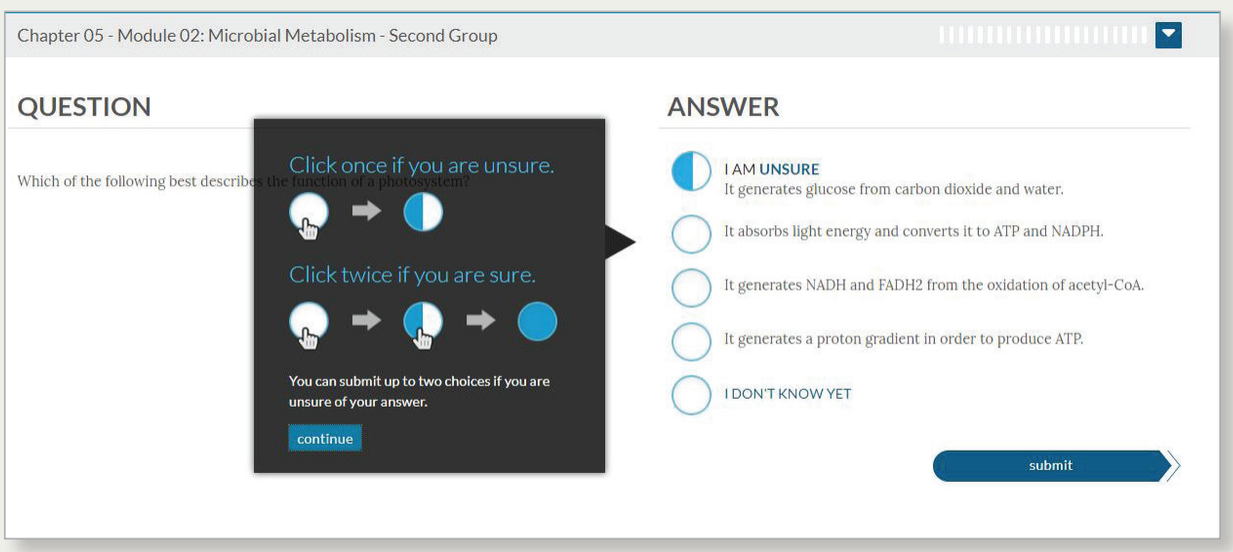
NEW! Before You Begin Questions help students revisit critical chemistry and biology knowledge for their success in this course. Discover them in Chapter Openers and in Mastering Microbiology where they are interactive providing feedback with embedded hints. This just-in-time remediation allows students to fill their own skill gaps before reading the chapter.

NEW! Micro Checks allow students to assess their understanding as new concepts are presented. These formative assessments are also assignable in Mastering Microbiology and include animations and videos to reinforce concepts and fill in skill gaps.

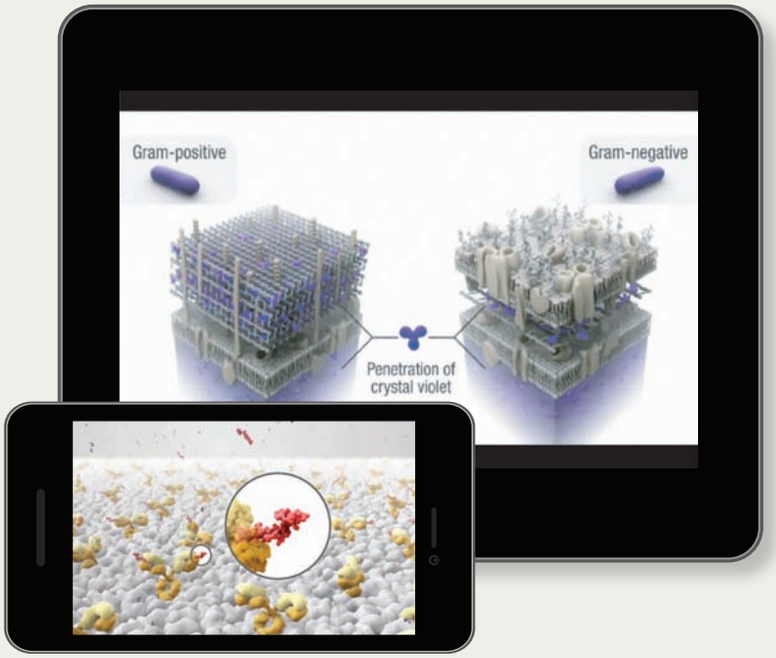
MICRO CHECK

1. During which reproductive process are gametes formed?
2. What is the difference between the results of mitosis and meiosis?
3. How many daughter nuclei are produced by mitosis in contrast to the number produced by meiosis?
4. How are coenocytes formed?

Most favored by students! 60% of students use Dynamic Study Modules . . . even when not assigned for test preparation. Adaptive learning technology from the most recent cognitive science allow students to practice their knowledge of course topics in a fun and positive format, building confidence. Topics progress in difficulty based on Bloom's Taxonomy, and students are provided just-in-time learning resources to review where needed.



Connect Lecture and Lab

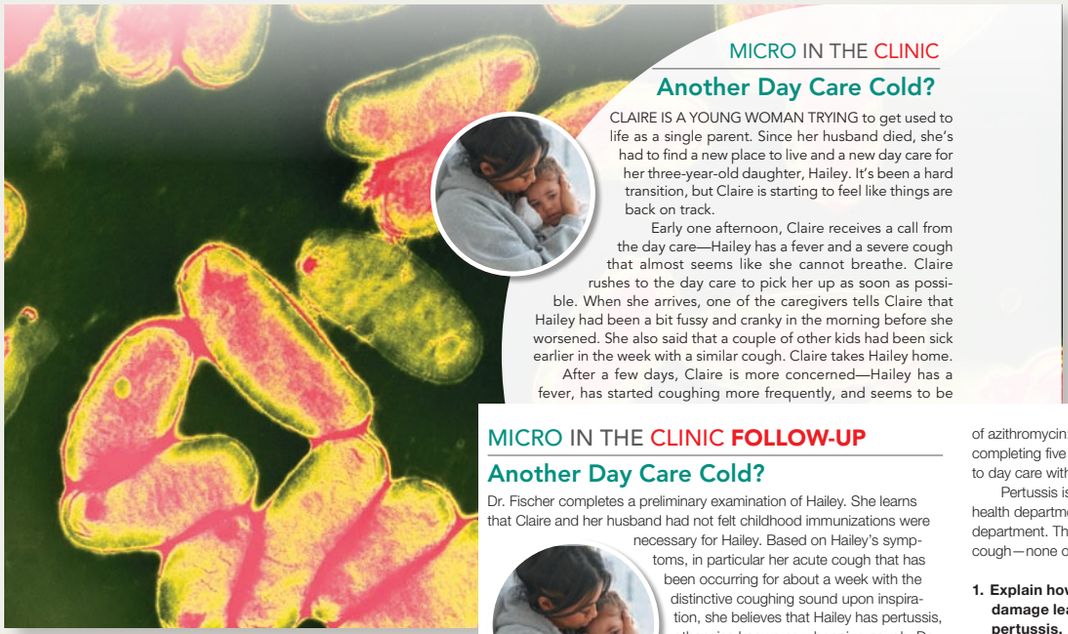


Micro Lab Tutor Videos and Coaching Activities help instructors and students get the most out of lab time. Students can practice their lab skills virtually, reviewing proper lab techniques with real-world applications. Live action video combined with molecular animation with assessment and feedback coach students how to interpret and analyze different lab results.

Lab Technique Videos give students an opportunity to see techniques performed correctly and quiz themselves on lab procedures both before and after lab time, improving confidence and proficiency. Assign as pre-lab quizzes in Mastering Microbiology and include coaching and feedback on theses lab techniques:

- NEW! The Scientific Method
- NEW! How to Write a Lab Report
- Acid-Fast Staining
- Amylase Production

Why Microbiology Matters in Health Care



MICRO IN THE CLINIC

Another Day Care Cold?

CLAIRE IS A YOUNG WOMAN TRYING to get used to life as a single parent. Since her husband died, she's had to find a new place to live and a new day care for her three-year-old daughter, Hailey. It's been a hard transition, but Claire is starting to feel like things are back on track.

Early one afternoon, Claire receives a call from the day care—Hailey has a fever and a severe cough that almost seems like she cannot breathe. Claire rushes to the day care to pick her up as soon as possible. When she arrives, one of the caregivers tells Claire that Hailey had been a bit fussy and cranky in the morning before she worsened. She also said that a couple of other kids had been sick earlier in the week with a similar cough. Claire takes Hailey home.

After a few days, Claire is more concerned—Hailey has a fever, has started coughing more frequently, and seems to be

Micro In the Clinic proposes real clinical scenarios at the beginning of each chapter. Students remain curious and engaged throughout the chapter as they learn the microbiology behind the case, and the chapter closing **Micro In the Clinic Follow-Up** provides the case result.

MICRO IN THE CLINIC **FOLLOW-UP**

Another Day Care Cold?

Dr. Fischer completes a preliminary examination of Hailey. She learns that Claire and her husband had not felt childhood immunizations were necessary for Hailey. Based on Hailey's symptoms, in particular her acute cough that has been occurring for about a week with the distinctive coughing sound upon inspiration, she believes that Hailey has pertussis, otherwise known as whooping cough. Dr. Fischer collects a nasopharyngeal swab to send for laboratory confirmation.

Dr. Fischer tells Claire that Hailey most likely became infected at day care. It is a highly infectious disease that is transmitted via droplets from infected persons. Because Hailey isn't immunized against the bacterium that causes the disease, *Bordetella pertussis*, she was susceptible to infection.

The lab analysis confirms Dr. Fischer's diagnosis. Because Hailey's pertussis was diagnosed relatively early, Dr. Fischer prescribes a course of azithromycin: 500 mg the first day, then 250 mg for four days. After completing five days of antibiotics, Hailey should be able to safely return to day care without spreading the disease further.

Pertussis is a mandatory reportable disease to the state and local health departments, so Dr. Fischer reports the case to her local health department. The other sick kids at the day care also had whooping cough—none of them had been immunized against pertussis.

1. **Explain how *B. pertussis* affects the trachea and how this damage leads to the characteristic cough associated with pertussis.**
2. **Hailey's infection could have been prevented with the DTaP vaccine. Hailey's parents' argument against the vaccine was that immunization was a personal choice that affected only Hailey. As a future health care professional, do you agree with Claire's argument? Why or why not?**

Check your answers to Micro in the Clinic Follow-Up questions in the Mastering Microbiology Study Area.

SOLVE THE PROBLEM

Rights versus Responsibilities

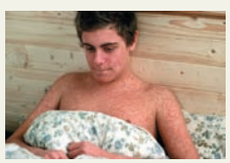
In the early 20th century, almost all children contracted measles, with 4 million new infections per year, resulting in approximately 50,000 hospitalizations and 6,000 deaths. But in 2000, the Centers for Disease Control and Prevention (CDC) declared measles eliminated (defined by lack of disease transmission for a year) in the United States. This medical advance capped a campaign of immunization that began in 1963. However, multiple measles outbreaks, beginning in 2014, resulted in the greatest number of cases of measles in the United States since 1995. How did measles reemerge? Several factors contributed.

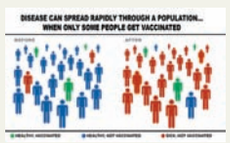
Measles is still common in other parts of the world, and travelers can bring the measles virus here. A measles outbreak occurs when there are significant numbers of unimmunized people in a community. When the immunization rate in a community is above 95 percent, then even unimmunized individuals are protected because susceptible people are too rarely in contact with infected individuals to allow disease transmission. This effect is called herd immunity. The currently recommended vaccine against measles is MMR, which protects against measles, mumps, and rubella. One dose is to be given at age 12–15 months, followed by a booster at 4–6 years, and a second booster between 19 and 40.

There is no controversy in the scientific community on MMR efficacy: the vaccine is highly effective. However, there is an ethical dilemma between the individual **rights** of people to refuse immunization as compared to their **responsibility** toward public health, since lack of immunization can allow the virus to spread, resulting in outbreaks.

If you were on a panel advising the CDC, how would you answer these questions?

1. **Should we force people to be immunized?**
2. **What procedures should be used to ensure the highest immunization rates?**
3. **What other facts would help make decisions related to immunization?**





Solve the Problem boxes are problem-based learning explorations of current microbiological challenges. Paired active learning instructor activities and Mastering Microbiology assessments encourage critical thinking.

Sweat the Small Stuff

CLINICAL CASE STUDY

Evaluating an Abnormal CBC

CBC Profile

Name: Brown, Roger — Age/Sex: 61/M — Attend Dr: Kevin, Larry
Acct#: 04797747 — Status: ADM IN
Reg: 11/27/12

SPEC #: 0303:AS:H00102T — COLL: 12 / 03 / 12-0620 — STATUS: COMP
RECD: 12 / 03 / 12-0647 — SUBM DR: Kevin, Larry

ENTERED: 12 / 03 / 12-0002 — OTHER DR: NONE, PER PT
ORDERED: CBC W / MAN DIFF — REQ #: 01797367

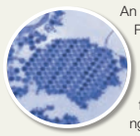
Test	Result	Normal range
CBC		
WBC (white blood cells)	0.8	4.8–10.8 K/mm3
RBC (red blood cells)	3.09	4.20–5.40 M/mm3
HGB (hemoglobin)	9.6	12.0–16.0 g/dL
HCT (hematocrit)	28.2	37.0–47.0 %
MCV	91.3	81.0–99.0 fL
MCH	31.1	27.0–31.0 pg
MCHC	34.1	32.0–36.0 g/dl
RDW	17.1	11.5–14.5 %
PLT (platelets)	21	150–450 K/mm3
MPV	8.7	7.4–10.4 fL
DIFF		
CELLS COUNTED	100	#CELLS
SEGS	39	
BAND	4	
LYMPH (lymphocytes)	41	
MONO (monocytes)	15	
EOS (eosinophils)	1	
NEUT# (# neutrophils)	0.3	1.9–8.0 K/mm3
LYMPH#	0.3	0.9–5.2 K/mm3
MONO#	0.1	0.1–1.2 K/mm3
EOS#	0.0	0–0.8 K/mm3
PLATELET EST	DECREASED	

Roger Brown, an African American cancer patient, received a chemotherapeutic agent as a treatment for his disease. The drug used to destroy the cancer also produced an undesirable condition known as *bone marrow suppression*. The complete blood count (CBC) profile shown here indicates that this patient is in trouble. Review the lab values, and answer the following questions.

1. **Note that the platelet count is very low. How does this**

EMERGING DISEASE CASE STUDY

Chikungunya



Crystal of chikungunya viruses.

An old man arrived at the doctor's office in Ravenna, Italy, with a combination of signs and symptoms the physician had never heard of: a widespread, itchy rash covering both arms and trunk; difficulty in breathing; high fever; nausea; and extreme joint pain. Chikungunya (chik-en-gun´ya) had arrived in Europe. Though scientists had known of chikungunya virus, which is related to equine encephalitis viruses, for over 50 years, most considered the tropical disease benign—a limited, mild irritation, not a catastrophe. Therefore, few researchers studied chikungunya virus or its disease. Now, they know better.

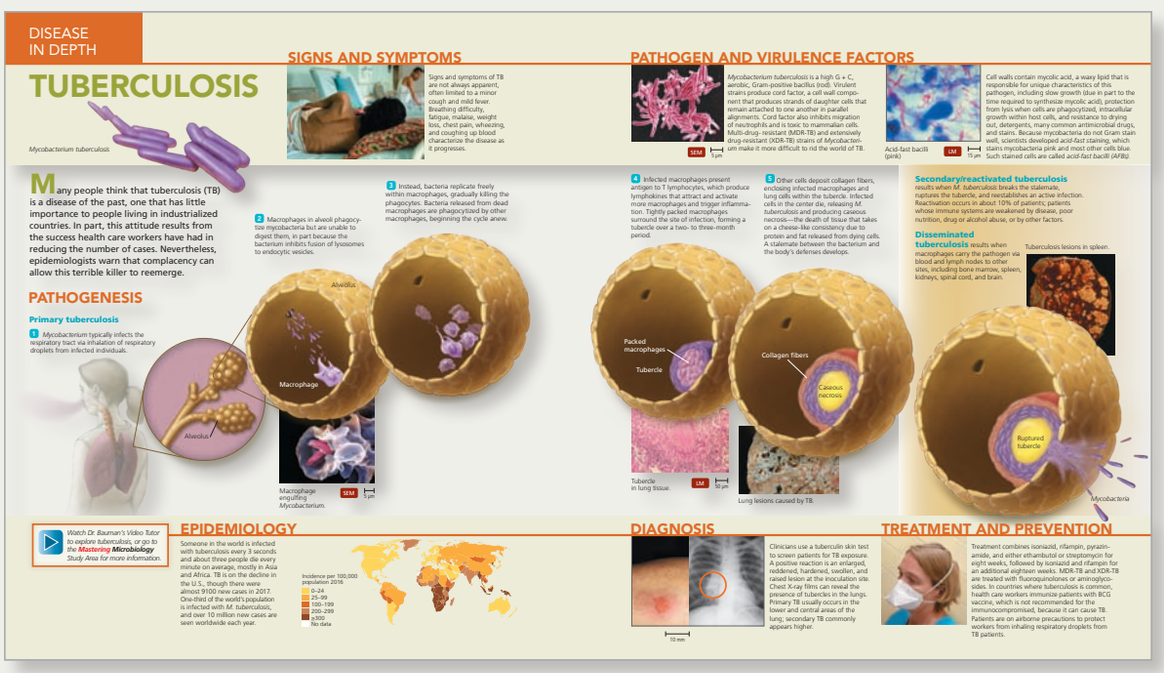
Over the past decade, chikungunya virus has spread throughout the nations of the Indian Ocean and across Africa. In 2006, officials on the French-owned island of La Réunion in the Indian Ocean reported 47,000 cases of chikungunya in a single week! That same year chikungunya reemerged in India for the first time in four decades with more than 1.5 million reported cases, and in 2010 it emerged in China. Why?

Aedes albopictus (Asian tiger mosquito), one species of *Aedes* that carries the virus, has moved into temperate climates, including Europe and the United States, as the climate has warmed. With the mosquito comes the possibility of viral proliferation—the insects have spread the tropical disease as far north in Europe as France.

And our Italian patient? His crippling pain lasted 10 days, but he survived. Now that he knows about mosquito-borne chikungunya, he insists that his family and friends use mosquito repellent liberally. Officials in the rest of Europe and in the United States join in his concern: With the coming of *Ae. albopictus*, is incurable chikungunya far behind?

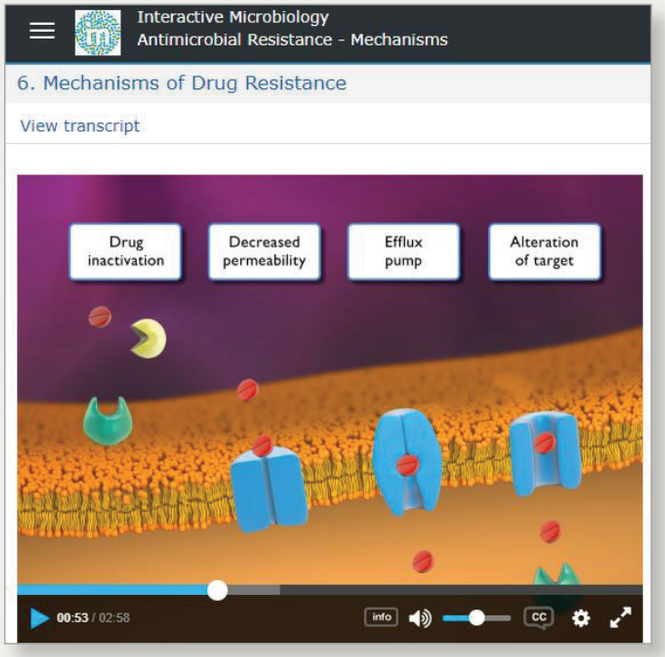
1. **Besides using repellents, how can people protect themselves from mosquito-borne pathogens?**
2. **Why is *Aedes* commonly known as the tiger mosquito?**
3. **Why aren't antibiotics such as penicillin, erythromycin, and ciprofloxacin effective in preventing and treating chikungunya?**

Clinical Case and Emerging Disease Case Studies discuss a patient's experience with a microbial disease and conclude with questions for the student to consider.



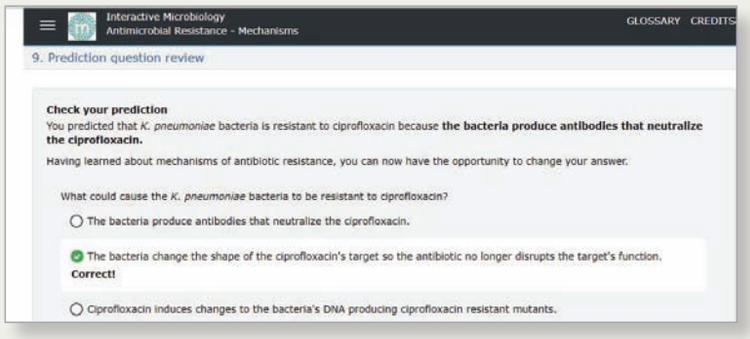
Disease in Depth Eleven complex diseases are presented in a visual layer highlighting the entire cycle of the disease encouraging students to think critically. Accompanying Video Tutors are provided in Mastering Microbiology.

Expand and Apply Learning in Mastering Microbiology™

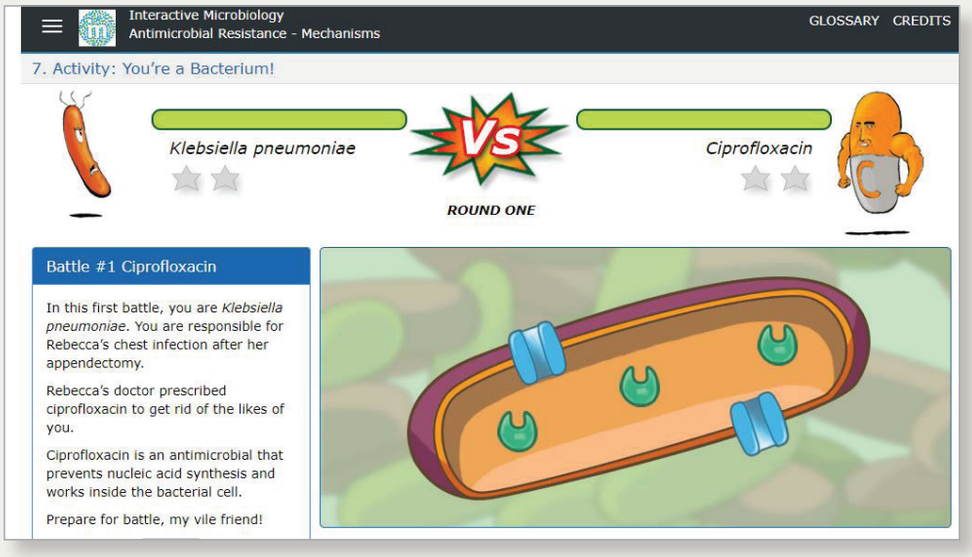


NEW! Interactive Microbiology is a dynamic suite of interactive tutorials and animations that present concepts within a real helathcare scenario emphasizng problem solving. Topics include Antimicrobial Resistance, Human Microbiota, Operons, Biofilms and Quorum Sensing, Complement, and more.

Make and Check Predictions. Formative and summative assessments encourage students to think critically as they make and check predictions.



Predict Outcomes in a fun and engaging format! Students are presented with a clinical scenario that allows them to manipulate variables that change outcomes in a fun and engaging learning activity.



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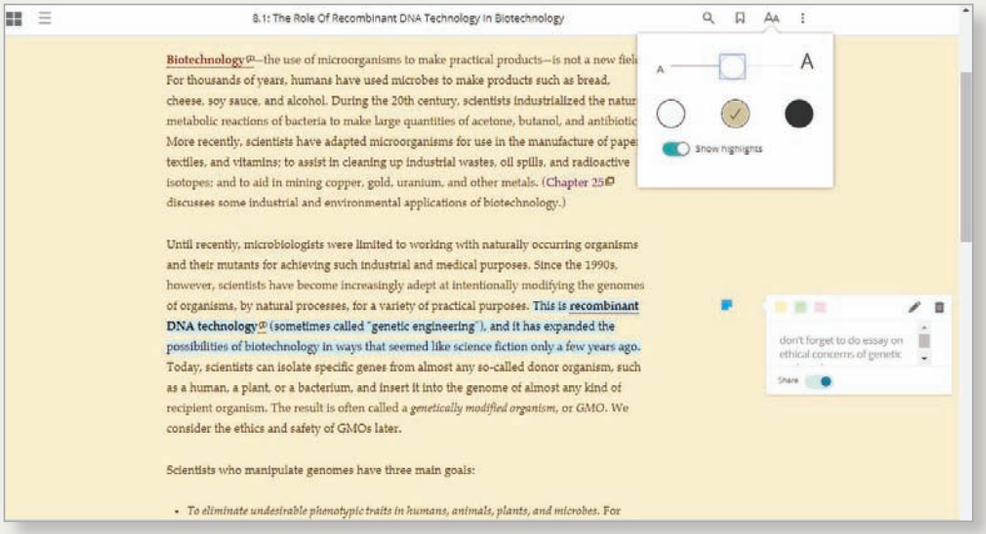
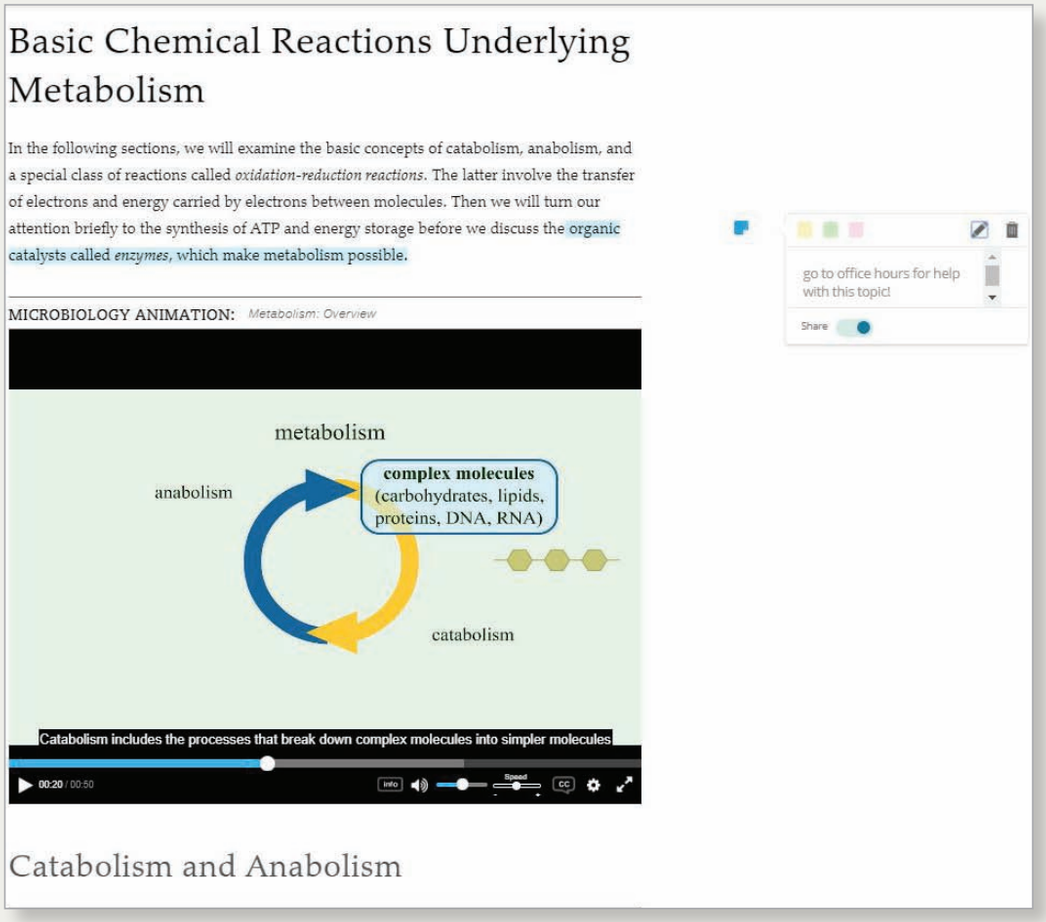


Pearson eText is a simple-to-use, mobile-optimized, personalized reading experience available within Mastering. It allows students to easily highlight, take notes, and review key vocabulary all in one place—even when offline. Seamlessly integrated videos and other rich media engage students and give them access to the help they need, when they need it. Pearson eText is available within Mastering when packaged with a new book; students can also purchase *Mastering with Pearson eText* during the student registration process.

Instructors can rearrange the table of contents at the chapter and section level to match the way they teach. It's easy for instructors to share their notes and highlights with students to add their personal teaching style to important topics, call out need-to-know information, or clarify difficult concepts. Further, the dashboard lets educators see how students are working in their eTextbook so that they can plan more effective instruction in and out of class.



The *Very Best* Instructor Resources and Support

The following resources can be found within a Mastering Microbiology instructor account and are organized by chapter:

- Learning Catalytics is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics, instructors can assess student understanding in real time using open-ended tasks to probe student understanding. Learning Catalytics is included in a Mastering with eText student subscription.
- All fgures, photos, and tables from the textbook in both labeled and unlabeled formats
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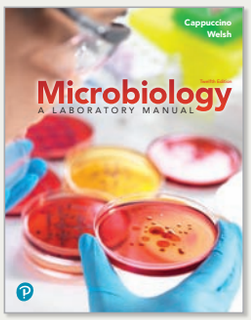
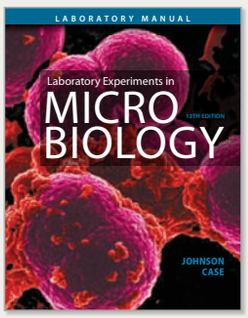
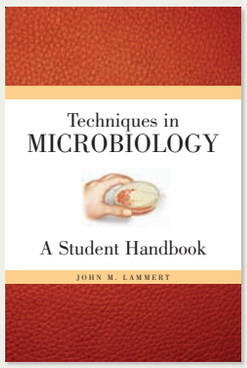


Cappuccino/Welsh's *Microbiology: A Laboratory Manual, 12e* is easy to adapt for almost any microbiology lab course. This versatile, comprehensive, and clearly written manual is competitively priced and can be paired with any undergraduate microbiology text. Known for its thorough coverage, straightforward procedures, and minimal equipment requirements, this lab manual incorporates current safety protocols from governing bodies such as the EPA, ASM, and AOAC.



Johnson/Case's *Laboratory Experiments in Microbiology, 12e* features 57 thoroughly class-tested and easily customizable exercises that teach basic microbiology techniques and applications. The manual provides comprehensive coverage of every area of microbiology for undergraduate students across diverse disciplines, including the biological sciences, allied health sciences, agriculture, environmental science, nutrition, pharmacy, and various pre-professional programs.

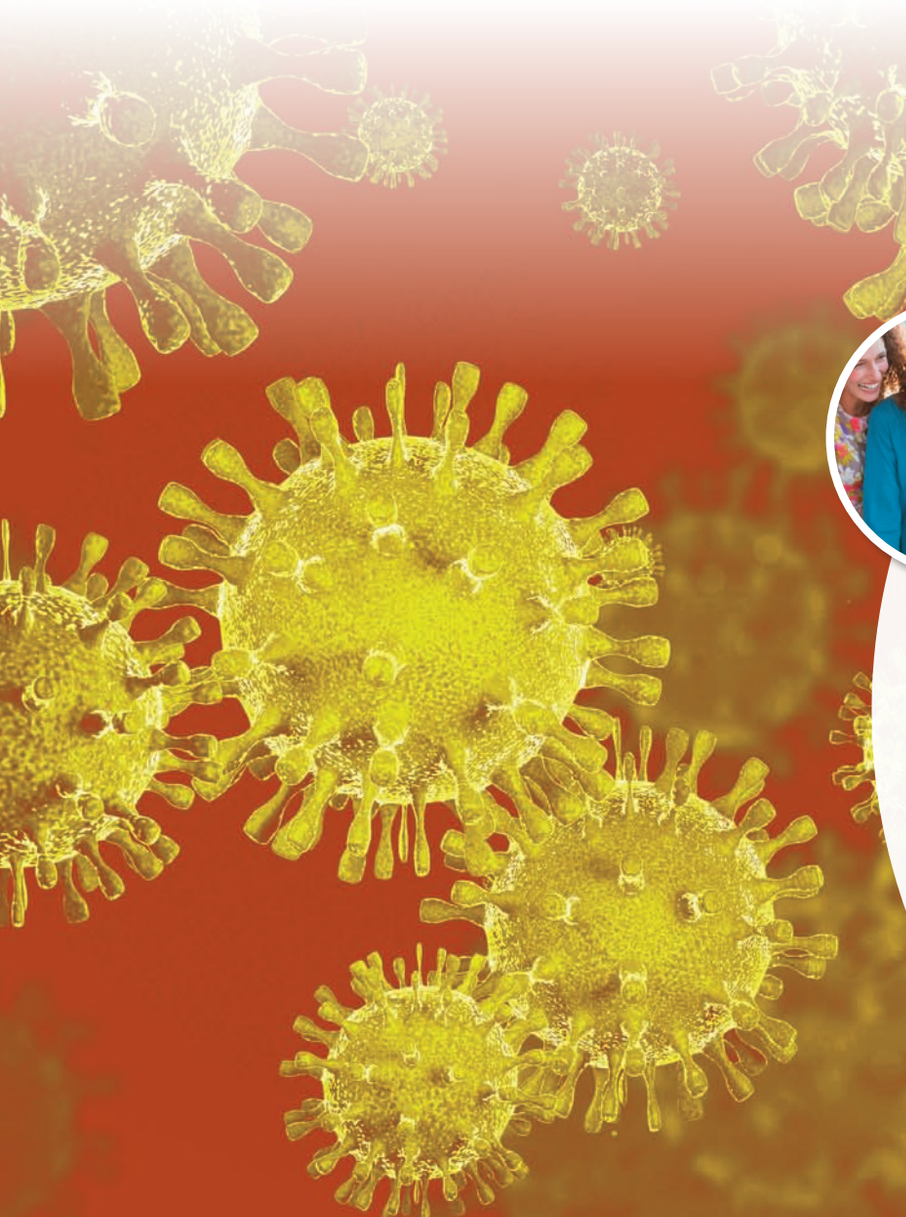


Lammert's *Techniques in Microbiology* is visual and incorporates "voice balloons" that keep the student focused on the process described. The techniques are those that will be used frequently for studying microbes in the laboratory, and include those identified by the American Society for Microbiology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

1 A Brief History of Microbiology

Before You Begin

1. What does the science of microbiology study?
2. Are most microorganisms harmful or harmless to people?



Our microbial world can appear beautiful, as shown in this artist's rendition of *Norovirus*.

MICRO IN THE CLINIC

Too Much Cake, or Something Worse?

PATTY IS A MOTHER TO 14-YEAR-OLD twins and works full time. Between her own job, driving her kids to practices and events, and spending time with her husband, Patty is constantly on the go. This past weekend was no exception. On Friday night, her office group went out for happy hour to celebrate a colleague's promotion. They had a great time—eating sushi, drinking wine, and relaxing. Saturday morning, her daughter's soccer team had a brunch, and in the afternoon her son's Little League team had an end-of-the-season barbecue. Saturday night she felt a little bit bloated but thought it was from the all the food she had eaten at the brunch—she was so full from the brunch that she had eaten only fruit salad at the barbecue.

Late Sunday afternoon, Patty and her husband returned home from his sister's birthday party. As they began to prepare dinner, Patty started to have a stomachache and felt a bit nauseated. She suspected it was from eating too much birthday cake; however, when she woke up in the middle of the night with diarrhea, she thought it might be something more than the cake. Monday morning Patty was unable to go to work—she had a terrible headache, and the diarrhea had lasted all night long. When she starts vomiting early Monday afternoon, she decides that she needs to go to the doctor.

1. **Is it just a case of too much cake?**
2. **What else could be causing Patty's symptoms?**

Turn to the end of the chapter (p. 22) to find out.

SOLVE THE PROBLEM

Smallpox: To Be or Not To Be?

Smallpox is likely the worst infectious disease of all time, killing an estimated 300 million people in the 19th century alone. It is a terrifying killer, with a death rate as high as 33% and the survivors carrying lifelong scars.

British medical doctor Edward Jenner is credited with inventing smallpox vaccination—the world's first immunization. On May 14, 1796, Jenner collected secretions from a cowpox sore on the hand of a milkmaid and rubbed them into scratches he made on the skin of an eight-year-old boy. Then, about a month later, he injected the boy with secretions from a lesion on a smallpox patient. The child did not get smallpox; he was immune. Jenner termed his technique *vaccination*, which comes from the Latin term for cow, *vacca.*

Medical doctors began vaccinating people with special two-pronged needles, and eventually smallpox was eradicated worldwide. The last case was documented on October 26, 1977.

Eradication represents one of the great triumphs of modern medicine, but smallpox virus itself still exists. Stocks are kept frozen in secure laboratories at the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia, and in the State Research Center of Virology and Biotechnology in Koltsovo, Russia.

Imagine you are assigned to be part of a team tasked to determine what to do with the world's remaining stores of smallpox virus.

- **Should governments and laboratories keep them?**
- **Or should they be destroyed? In other words, should we intentionally make a species extinct forever?**

Smallpox viruses

- **What facts do you need to make an informed decision?**
- **If the decision were to be made today, how would you vote?**

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.

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 van Leeuwenhoek.

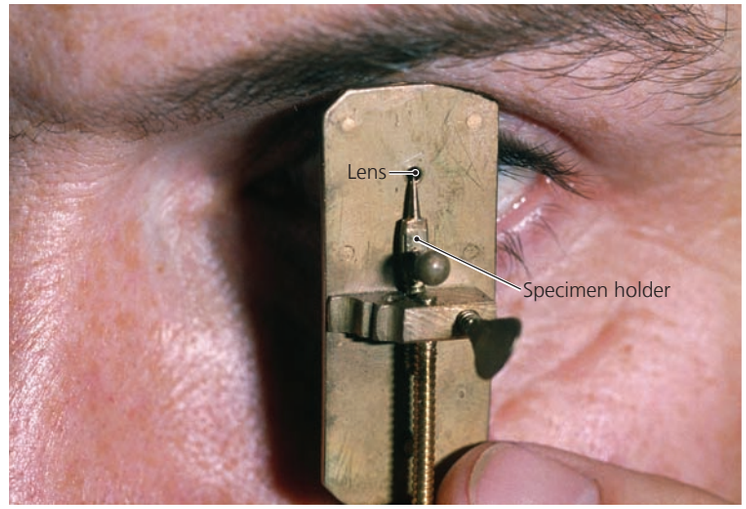
1.2 Define microbes in the words of van Leeuwenhoek and as we know them today.

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 clothier, merchant, and lens grinder, and the man who first discovered the bacterial world (**FIGURE 1.1**).

Van Leeuwenhoek was born in Delft, the Netherlands, and lived most of his 90 years in the city of his birth. What set van Leeuwenhoek apart from many other men of his generation was an unending curiosity coupled with an almost stubborn desire

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

Figure 1.1 *Protozoa are generally larger than bacteria.*



▲ **FIGURE 1.2 Reproduction of van Leeuwenhoek's microscope.** This simple device is little more than a magnifying glass with screws for manipulating the specimen, yet with it, van 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.

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. 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]

Van Leeuwenhoek had discovered the 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.

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

[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]Antoni van Leeuwenhoek, in a letter to the Royal Society of London for the Promotion of Natural Knowledge.

From the figure accompanying his report and the precise description of the size of these organisms from between his teeth, we know that van Leeuwenhoek was reporting the existence of bacteria. By the end of the 19th century, van 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, the Dutchman Antoni van Leeuwenhoek was elected to the Royal Society of London 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 van 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.)

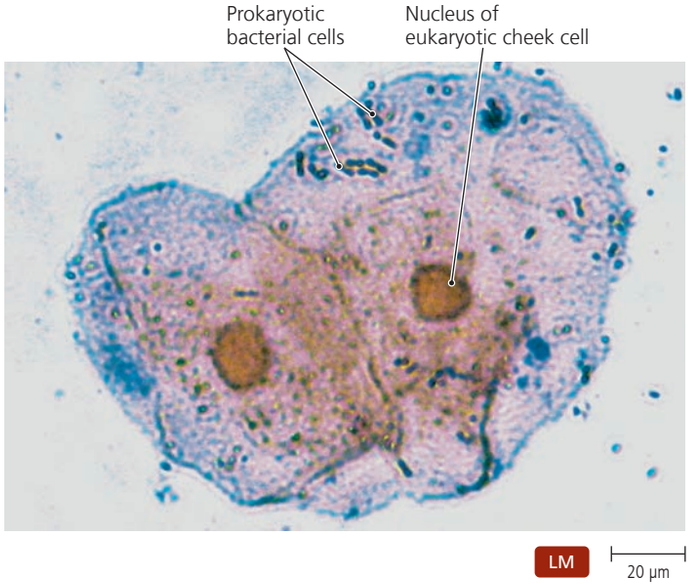
The microorganisms that van Leeuwenhoek described can be grouped into six basic categories: bacteria, archaea, fungi, protozoa, algae, and small multicellular animals. The only type of microbes not described by van Leeuwenhoek is *viruses*,[3] which are too small to be seen without an electron microscope. 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.)

[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.

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. Scientists first discovered archaea in extreme environments, such as the highly saline and arsenic-rich Mono Lake in California, acidic hot springs in Yellowstone National Park, and oxygen-depleted mud at the bottom of swamps. No archaea are known to cause diseases in humans.

Though bacteria may have a poor reputation, 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.

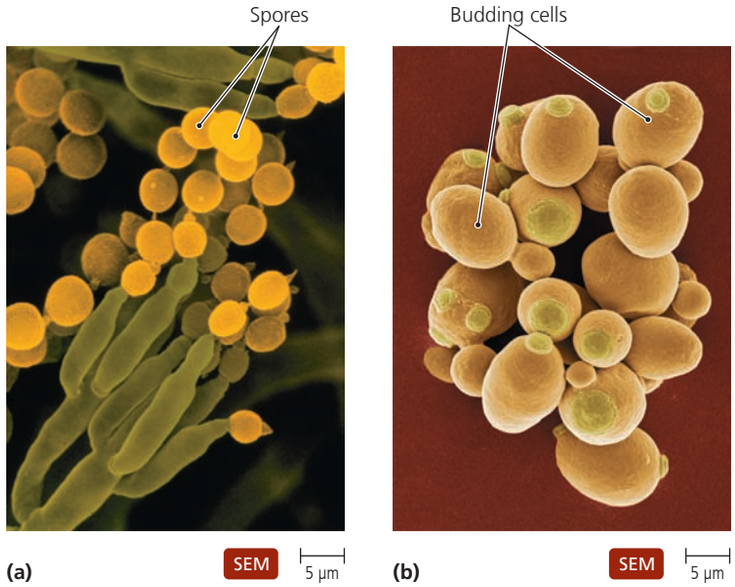
Fungi

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. Fungal cells differ from plant cells in that fungi obtain their food from other organisms (rather than making it for themselves). Fungal cells differ from animal cells 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.

[5]Plural of the Latin *fungus*, meaning "mushroom."

[6]From Greek *eu*, meaning "true," and *karyon*, meaning "kernel."



▲ **FIGURE 1.5 Fungi. (a)** The mold *Penicillium chrysogenum*, which produces penicillin, has long filaments that intertwine to form its body (not shown). It reproduces by spores. **(b)** The yeast *Saccharomyces cerevisiae*. Yeasts are round to oval and typically reproduce by budding.

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. 10). 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, as agents of human disease, and in food production.)

Protozoa

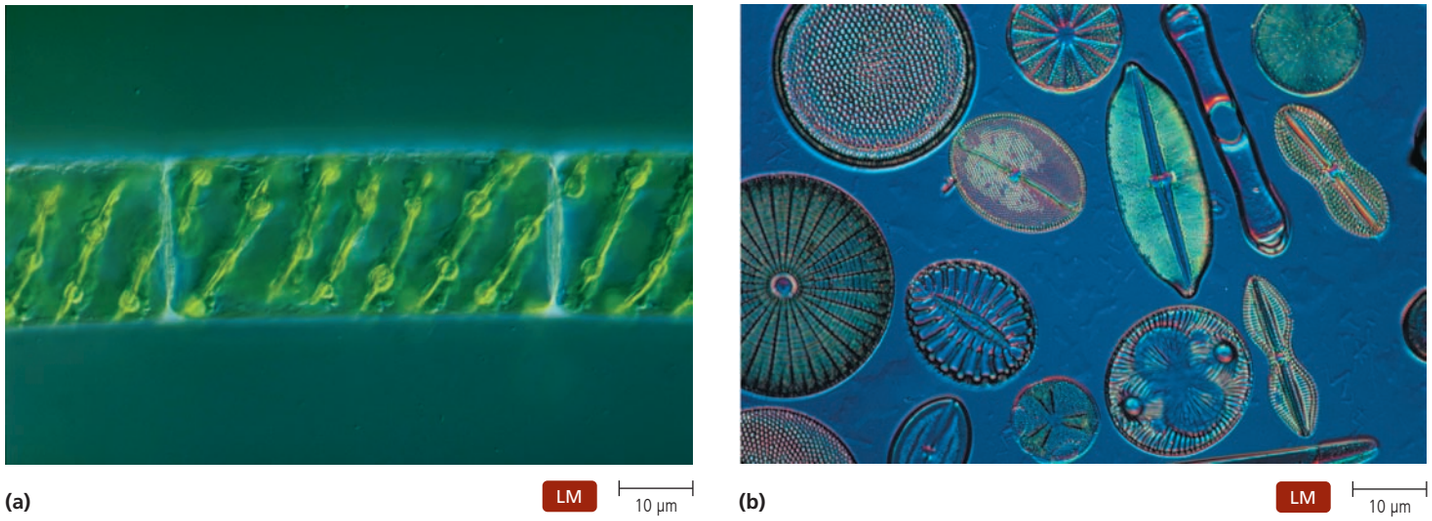
Protozoa are single-celled eukaryotes that are similar to animals in their nutritional needs and cellular structure. In fact, *protozoa* is Greek for "first animals," though scientists today classify them in their own groups rather than as animals. Most protozoa are capable of locomotion, and one way 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 a 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.

Many protozoa live freely in water, but some live inside animal hosts, where they can cause disease. Most protozoa reproduce

▲ **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 three individuals of *Peranema*. *How do cilia and flagella differ?*

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



▲ **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.

asexually, though some are sexual as well. (Chapters 12 and 23 further examine protozoa and some diseases they cause.)

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, while health professionals use them as lubricants. 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 much 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.)

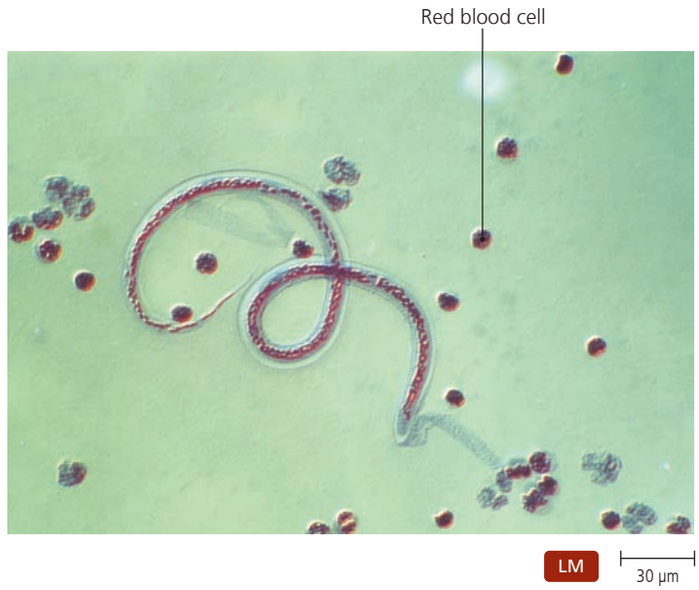
Other Organisms of Importance to Microbiologists

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.)

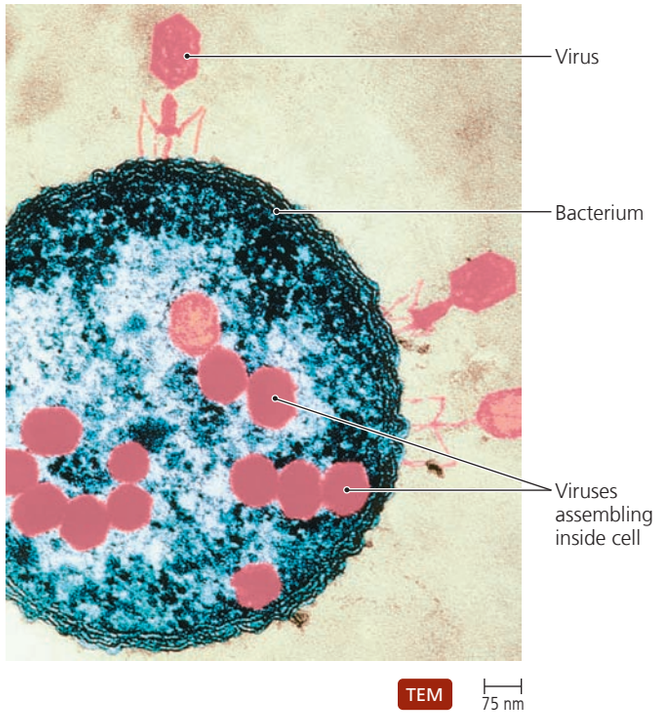
[10]Plural of the Latin *alga*, meaning "seaweed."

The only type of microbe that remained hidden from van 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.)

Van Leeuwenhoek first reported the existence of most types of microorganisms in the late 1600s, but microbiology did not develop significantly as a field of study for almost two centuries. There were a number of reasons for this delay. First, van Leeuwenhoek was a suspicious and secretive man. Though he



▲ **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.

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 van 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.

MICRO CHECK

1. What scientific device did van Leeuwenhoek create?
2. What is the modern name for organisms that are too small to be seen without a microscope?
3. Van Leeuwenhoek described bacteria, archaea, fungi, algae, small multicellular animals, and one other type of microorganism. What other type of microorganism did he describe?
4. All eukaryotic cells contain most of their genetic material inside what structure?

TELL ME WHY

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

The Golden Age of Microbiology

LEARNING OUTCOMES

1.6 List four questions that propelled research in what is called the "Golden Age of Microbiology."
1.7 Explain why some consider Pasteur to be the "Father 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 women and men of the era accumulated the experimental evidence that answered them.

Does Microbial Life Spontaneously Generate?

LEARNING OUTCOMES

1.8 Identify the scientists who argued in favor of spontaneous generation.
1.9 Compare and contrast the investigations of Redi, Needham, Spallanzani, and Pasteur concerning spontaneous generation.
1.10 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 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 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 view and adopt the idea that animals come only from other animals.

▲ **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 from the meat, and no maggots appeared there, although a few appeared on top of the gauze.

Needham's Experiments

The debate over spontaneous generation was rekindled when van 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 van Leeuwenhoek's "wee animalcules"; surely they did not have parents, did they? They must arise spontaneously.

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 life because he had heated the vials sufficiently to kill everything. Needham's experiments so impressed the Royal Society in Britain 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 centuries, 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.

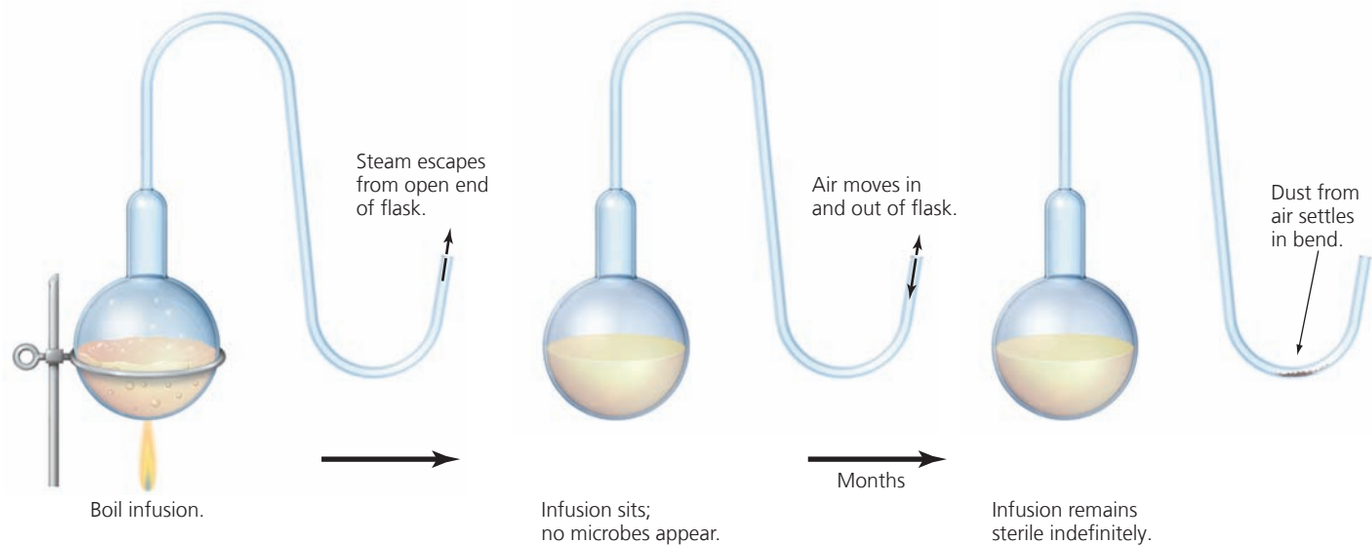
Pasteur's Experiments

Louis Pasteur (1822–1895) was a tireless 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.

[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.



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

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).

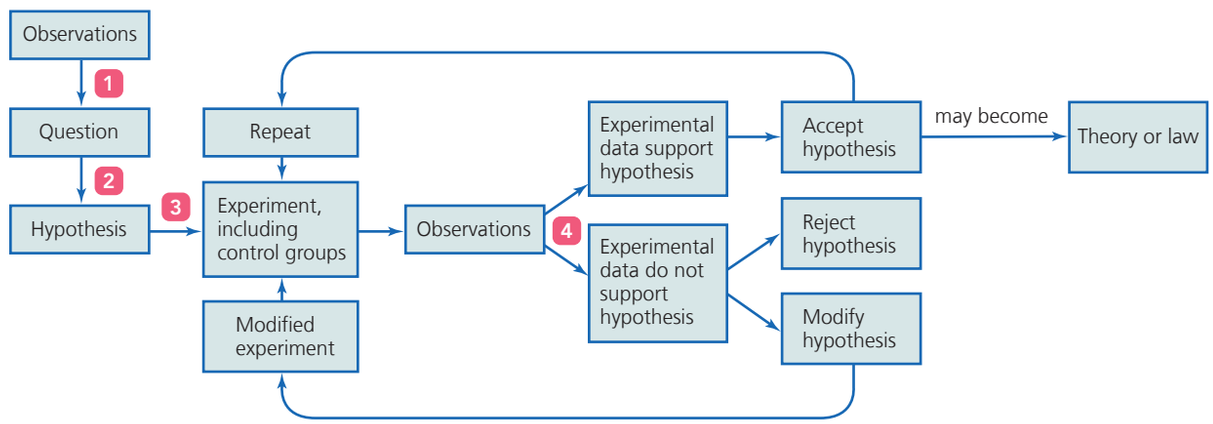
Crowded for space and lacking funds, he improvised an incubator in the opening under a staircase. Day after day, he crawled on hands and knees into this small space and examined his flasks for the cloudiness that would indicate the presence of living organisms. In 1861, he reported that his "swan-necked flasks" remained free of microbes even 18 months later. Because the flasks contained all the nutrients (including air) known to be required by living things, he concluded, "Never will spontaneous generation recover from the mortal blow of this simple experiment."

Pasteur followed this experiment with demonstrations that microbes in the air were the "parents" of Needham's microorganisms. He broke the necks off some flasks, exposing the liquid in them directly to the air, and he carefully tilted others so that the liquid touched the dust that had accumulated in their necks. The next day, all of these flasks were cloudy with microbes. He concluded that the microbes in the liquid were the progeny of microbes that had been on the dust particles in the air.

The Scientific Method

The debate over spontaneous generation led in part to the development of a generalized **scientific method** by which questions are answered through observations of the outcomes of carefully controlled experiments instead of by conjecture or according to the opinions of any authority figure. The scientific method, which provides a framework for conducting an investigation rather than a rigid set of specific "rules," consists of four basic steps (FIGURE 1.13):

1. A group of observations leads a scientist to ask a question about some phenomenon.
2. The scientist generates a hypothesis—that is, a potential answer to the question.
3. The scientist designs and conducts an experiment to test the hypothesis.
4. Based on the observed results of the experiment, the scientist either accepts, rejects, or modifies the hypothesis.



▲ **FIGURE 1.13 The scientific method, which forms a framework for scientific research.**