

# Preface

Welcome to the best learning resource in microbiology education today: the visually stunning 16th Edition of *Brock Biology of Microorganisms* (BBOM). The 16th Edition is the most student-friendly and accessible edition yet and presents the most exciting and recent picture of the science of microbiology available today. For three generations, both students and instructors alike have praised the accuracy, authority, consistency, and teachability of BBOM for exploring the principles of microbiology in a readable, connected, and visually appealing way.

Both students and instructors will benefit from at least four important strengths of the 16th Edition: (1) our approach of using cutting-edge research to solidify basic concepts; (2) the seamless integration of molecular and ecological microbiology with coverage of evolution, diversity, the immune system, and infectious diseases; (3) the spectacular art program complemented with striking and compelling photos; and (4) the wide assortment of teaching and learning tools that accompany the book itself. With an extremely strong author team that employs experts in each major theme, BBOM 16th Edition leads the way in presenting the essential principles of microbiology that students need to master today.

## What's New in the 16th Edition?

The 16th Edition guides students through the six major themes of microbiology as outlined by the American Society for Microbiology Conference on Undergraduate Education (ASMCUE): Evolution, Cell Structure and Function, Metabolic Pathways, Information Flow and Genetics, Microbial Systems, and the Impact of Microorganisms. With new and revised artwork complemented by over 60 new photos, BBOM 16th Edition (16e) presents microbiology as the visual science it is. Thirty-four new MicrobiologyNow chapter-opening vignettes were composed for this edition, each designed to introduce a chapter's theme through a recent discovery in the field of microbiology. These exciting accounts will naturally draw students into the chapter and show how the chapter's content connects with real-world problems. Several new Explore the Microbial World features were also developed for this edition, each designed to give students a feel for exciting special topics in microbiology and to fuel their scientific curiosity.

Genomics, and all of the various "omics" it has spawned, support content in every chapter of BBOM 16e, reflecting the reality of how omics has transformed all of biology, especially microbiology. The result is a robust and modern treatment of microbiology that guides students through the maze of omics with concrete examples of how these powerful tools have allowed microbiologists to probe deeper and farther into the microbial world than ever before.

To reinforce the learning experience, the 16e debuts a new pedagogical aid called Key Concepts. These brief summaries of each chapter part are written in clear and straightforward language that give students a heads-up as to what is coming in the following sections. Complementing

the Key Concepts, each numbered section is summarized in the chapter review and accompanied by a review question that links concept review with concept mastery.

BBOM 16e is supported by Mastering Microbiology, Pearson's online homework, tutorial, and assessment system that assists students in pacing their learning and keeps instructors current on class performance. Mastering Microbiology includes a new feature, Dynamic Study Modules, which adapt to the student's performance in real time to help each student's study of course topics. Students build the confidence they need to deepen their understanding, participate meaningfully, and perform better in and out of class. Other highlights include chapter-specific reading quizzes, MicroLab Tutorials, MicrobiologyNow coaching activities, Clinical Case and MicroCareer coaching activities, animation quizzes, MCAT Prep questions, and many additional study and assessment tools. Collectively, the content and presentation of BBOM 16e, coupled with the powerful learning tools of Mastering Microbiology, create an unparalleled educational experience in microbiology.

## Revision Highlights

### UNIT 1 The Foundations of Microbiology

#### Chapter 1

- The microbial world is introduced in an exciting and novel way by weaving together core concepts in microbiology with the historical events that led to their discovery. The foundations of microbiology are revealed through introductions to microscopy, laboratory cultivation, microbial evolution, and the molecular principles that unify all life.
- Some highlights: Vibrant new images help connect students with the diverse and numerous ways in which microbiology impacts our world. Coverage of cell size and morphology is introduced here rather than in Chapter 2 in order to draw students into the microscopic world early on and introduce them to actual microbes and their properties.

#### Chapter 2

- In the microbial world, cellular structures are tightly linked to cell functions, and Chapter 2 offers a complete guide to the features that define and differentiate microbial cells and their functions. Updated coverage of nutrient transport here rather than in the growth chapter places this critical cellular activity firmly within the context of the cell envelope.
- Some highlights: Electron cryotomography has provided new insight into cell biology and is incorporated in new views of peptidoglycan structure, S-layers, and diversity in cell envelope organization. Vivid new illustrations developed from cutting-edge

microscopic images of the flagellum, the archaellum, and the rotating proteins that confer gliding motility provide a fresh new look at how these structures move prokaryotic cells about their environments.

### Chapter 3

- This chapter remains focused on the fundamentals of metabolism and has been revised to simplify metabolic concepts and emphasize the modularity of metabolism. The chapter starts with the essential principles and then provides examples of their application while guiding the student through the major metabolic processes that define microbial life.
- Some highlights: New art provides greater clarity and realism in understanding electron transport reactions, making this process easier to understand and easier to teach. Modularity of metabolism and the importance of the proton motive force receive greater emphasis by providing simple examples of chemolithotrophy and phototrophy to reinforce the student's understanding of energy conservation as a unifying concept in biology. Updates to fermentation clarify and distinguish this process from anaerobic respiration, and an overview of autotrophy and nitrogen fixation emphasize the connectivity between anabolic and catabolic processes in the cell.

### Chapter 4

- This chapter on microbial growth and its control moves up one slot from the previous edition to better prepare students for dealing with concepts in molecular biology and genetics where microbial growth plays a central role.
- Some highlights: The essentials of microbial nutrition and laboratory culture are introduced here with a segue to counting methods and quantitative aspects of microbial growth. The dynamics of microbial growth are emphasized with exciting new coverage of the biofilm mode of growth and alternatives to binary fission. The latter includes organisms that display budding division such as *Caulobacter*—the prime model for developmental studies of bacteria—and bacteria that grow by hyphal extensions characteristic of filamentous bacteria such as *Streptomyces*, a major producer of antibiotics.

### Chapter 5

- This introduction to virology moves up from its position in Unit 2 in the previous edition to round out the foundations of microbiology theme of Unit 1. This move gives earlier visibility to the importance of viruses as microbes, clearly explains how they differ from cells, and lays the necessary groundwork for dealing with the genetics, genomics, and molecular biology that follows in Unit 2.
- Some highlights: Emphasis remains on the basic principles of virology including how viruses and cells can be viewed as both similar and different and how methods for replicating viruses resemble those for growing cells. Bacteriophage T4 is used as a model lytic virus, and coverage of eukaryotic viruses is expanded beyond just animal viruses to include some major viruses of plants. This highly visual chapter is embellished with over a dozen new photos of exciting, newly discovered viruses along with supporting art that underscores the fundamentals of virology.

## UNIT 2 Molecular Biology and Genetics

### Chapter 6

- Moved forward two slots from its position in the previous edition to better fit as the kick-off to Unit 2, this chapter lays the necessary groundwork in molecular biology for tackling microbial genetics and genomics and the fast-moving fields of synthetic biology, molecular microbial ecology and diversity, the human microbiome, and diagnostic microbiology.
- Some highlights: Reorganized coverage of DNA supercoiling precedes new and more realistic depictions of the seminal processes of replication, transcription, and translation. New coverage of transcriptional processes in *Archaea* and their relationship to those in *Eukarya* and updated coverage of protein secretion round out this essential primer in microbe molecular biology that every student needs to master.

### Chapter 7

- Because microbes must coordinate cellular processes to optimize their chances for survival and reproduction, Chapter 7 is central to Unit 2 in describing how prokaryotic cells control the seminal processes of replication, transcription, and translation. Microbial regulatory systems are highly diverse and sometimes tiered, but an appreciation for how control systems work is key to understanding metabolic diversity, pathogenesis, and synthetic biology.
- Some highlights: Reorganized and expanded coverage of gene expression in *Bacteria* and *Archaea* including activation and repression/derepression as well as chemotaxis and global controls. New coverage of two-component systems for regulating nitrogen assimilation and updated coverage of the phosphate regulon, heat shock response, and riboswitch activity exemplify the comprehensive nature of this chapter.

### Chapter 8

- This chapter continues the molecular theme of Unit 2 by building on the major topics of Chapters 4, 6, and 7 in the context of the mechanisms that underlie microbial growth and differentiation. Knowledge of the molecular biology of microbial growth is central to mastering the biology of microbial populations and is keenly relevant to the topics of antibiotic efficacy, antibiotic resistance and persistence, and infectious disease microbiology in general.
- Some highlights: New high-resolution time-course images highlight the molecular processes of growth and cell shape determination. We expand coverage of biofilm formation and the signaling molecule cyclic-di-GMP in *Bacteria* and provide new coverage of biofilm formation in *Archaea*. The chapter also includes new coverage of endospore germination and phenotypic heterogeneity to encompass more topics within the evolving field of microbial growth from a molecular perspective.

### Chapter 9

- This chapter rounds out Unit 2 by discussing the foundation for microbial diversity—how microbes undergo genetic change while still maintaining genomic integrity. This essential primer of microbial genetics also lays the groundwork for tackling the hot areas of

microbial omics and synthetic biology and provides the fundamental background necessary to comprehend the most recent concepts of microbial evolution that will unfold in later chapters.

- Some highlights: New and updated visual depictions of DNA exchange between microbes as well as updated coverage on natural competence and the role of pili in DNA uptake. Reorganized and new coverage of barriers to DNA transfer including CRISPR, the important bacterial and archaeal “immune system” whose applications are revolutionizing biology and clinical medicine.

## UNIT 3: Genomics, Synthetic Biology, and Evolution

### Chapter 10

- Because the genome is the blueprint for all biological traits, this chapter kicks off Unit 3 by discussing not only microbial genomics, but also methods to assay large pools of biological molecules. Various omics studies can be combined to provide a detailed picture of the vast range of capabilities possessed by a specific microbe or groups of microbes, which is essential to the topics of genetic engineering, synthetic biology, and microbial ecology.
- Some highlights: New and exciting coverage of functional genomics and high-throughput techniques to determine the role of individual genes. Reorganized and updated coverage of microbial genome content, proteomic applications, and systems biology highlight the ever-advancing field of omics.

### Chapter 11

- This chapter continues the theme of Unit 3 by focusing on the unique genomes of viruses and the diverse mechanisms by which viral genomes are replicated. Knowledge of the molecular biology underlying viral replication is central not only to understanding how viruses infect their hosts and how they persist, but also for developing new clinical strategies for treating viral diseases of humans and other animals.
- Some highlights: New coverage of viral taxonomy precedes updated coverage of viruses that infect *Archaea*. Reorganized topics of bacteriophage genome replication and regulation of lysogeny in lambda directly link to foundational material in Chapter 5.

### Chapter 12

- This high-energy chapter entitled “Biotechnology and Synthetic Biology” covers the essential tools of twenty-first-century biotechnology and describes how they have been applied to yield game-changing medical and other commercial products from the activities of genetically engineered microbes. Expanded coverage is provided of the rapidly advancing fields of synthetic biology and CRISPR genome editing—the latest revolutions to hit biology since discovery of the polymerase chain reaction (PCR). Text and art have been updated throughout.
- Some highlights: New coverage of how biobricks contribute to the construction of synthetic pathways and synthetic cells; the use of recombineering to revolutionize molecular cloning; genetically engineered delivery of human therapeutic agents; refactoring metabolic pathways; targeted microbial delivery of human drugs; and how gene drives could finally conquer malaria.

### Chapter 13

- This chapter on microbial evolution was moved from the diversity unit into Unit 3 to emphasize its now closer ties to the unit theme of genomics. In addition to origin of life coverage, the chapter now focuses on how evolution affects the genome and ultimately the biology of the organism. The chapter ends with streamlined coverage of microbial systematics and the definition of a microbial species as a prelude to coverage of microbial diversity in Unit 4.
- Some highlights: New and expanded coverage of the evolution of both cells and viruses, including new art on cellular origins from hydrothermal systems and early bioenergetics; more extensive discussion of the mechanisms of microbial evolution from a genomic perspective, including genomic changes that occur during both vertical and horizontal gene transmission; broadened coverage of experimental evolution and genome dynamics.

## UNIT 4 Microbial Diversity

### Chapter 14

- Recent years have seen a flurry of fundamental new discoveries about how anaerobic organisms conserve energy. Chapter 14 has been updated to integrate information from new discoveries that lie at the heart of diverse metabolic pathways, including the discovery of electron bifurcation and energy-converting hydrogenases.
- Chapter 14 now includes a new introductory section that summarizes foundational principles of microbial physiology. This new section boils the diversity of the microbial world down into a few key principles that students can follow throughout the chapter. In addition, the chapter includes new art illustrating electron bifurcation, as well as electron flow in organisms such as sulfate reducers and methanogens. Old favorites throughout the chapter are also updated to account for recent discoveries in the field.

### Chapter 15

- Chapter 15 has been reorganized and updated to emphasize relationships between metabolic and ecological diversity. New photos have been added to emphasize the morphological diversity of anoxygenic phototrophs and to demonstrate how microorganisms work together to modify their environments.

### Chapter 16

- Chapter 16 has new coverage of difficult-to-cultivate bacteria, such as *Acidobacteria*, *Planctomycetes*, and *Fusobacteria*. The widespread application of metagenomic techniques have revealed that these *Bacteria* are of considerable importance in a range of habitats, including the human microbiome, but have only recently been obtained in laboratory culture.

### Chapter 17

- Metagenomics has contributed greatly to our knowledge of archaeal diversity. Chapter 17 now exploits this and unveils the TACK, DPANN, and Asgard *Archaea*, some of which are the closest known relatives of the eukaryotes. We also update the diversity of mechanisms of methanogenesis in the archaeal domain.

## Chapter 18

- Along with major updates on eukaryotic phylogeny, a new section is devoted to the haptophytes, including the globally and ecologically important coccolithophore *Emiliana huxleyi*. Coccolithophores play a major role in regulating global climate, illustrating the power that microbes exert over our biosphere.

## UNIT 5 Microbial Ecology and Environmental Microbiology

### Chapter 19

- The chapter begins a unit on ecology and environmental microbiology. The modern tools of the microbial ecologist are described with examples of how each has helped sculpt the science.
- Some highlights: A new method to visualize protein synthesis in single cells allows study of microbial activity in the environment. Metabolomics exploits new methods in mass spectrometry to unravel the complex metabolic interactions sustaining microbial communities. Nanosensor technologies are revealing how microbes alter the chemical landscape of three-dimensional surfaces. A new section explores multi-omics, which combines multiple state-of-the-art analytical tools to more fully characterize microbial communities.

### Chapter 20

- The properties and microbial diversity of major microbial ecosystems including soils and aquatic systems are compared and contrasted in exciting ways.
- Some highlights: Expansive coverage of surface-attached microbial communities and how those communities are responding to plastic pollution of the environment. New understanding of the ecology of iron-oxidizing bacteria revealed by the isolation of new members of this biogeochemically significant group. The discovery in deep ocean sediments of novel *Archaea* that link this domain with *Eukarya*. Extensive coverage of marine viruses, their abundance and diversity, and how they alter the physiology of organisms they infect. Humans traveling to 10,000-meter depths in the oceans discover the most pressure-tolerant bacterium known.

### Chapter 21

- Extensive coverage of the major nutrient cycles in nature and the microbes that catalyze them are presented in a fashion that allows the cycles to be taught as individual entities or as interrelated metabolic loops.
- Some highlights: Expanded coverage of the biogeochemistry of sulfur compounds highlights the importance of volatile microbial products such as dimethyl sulfide for cloud formation. Advances in the biochemistry of extracellular electron transfer add new understanding to how the ecology and diversity of microorganisms drive the biogeochemical cycling of iron and manganese. The mystery of how methane is generated (typically a strictly anoxic process) in highly oxygenated ocean surface waters is solved by discoveries in the phosphorus cycle described in a new Explore the Microbial World.

## Chapter 22

- This chapter on the built environment shows how humans create new microbial habitats through construction of buildings, supporting infrastructure, and habitat modification, and which microbes take advantage of these habitats and why.
- Some highlights: The microbial metabolism of biologically produced and manufactured chlorinated organics has been expanded, as has the basis for the bioremediation of major chemical pollutants. How microbes are responding to the mountains of plastics contaminating the environment and the discovery of novel bacteria capable of degrading plastic bottles are described. New technology that improves the efficiency of wastewater treatment using granular sludge technology is presented, and the microbial response to the excessive use of common household cleansers is considered.

## Chapter 23

- A chapter devoted to nonhuman microbial symbioses describes the major microbial partners that live in symbiotic associations with other microbes, with plants, and with animals other than humans.
- Some highlights: Newly revised section on symbioses between microorganisms addresses the ecological significance of phototroph switching in lichens and how certain bacterial species use electrically conductive structures to form intimate symbiotic associations. Several updates include how insect symbionts are used to combat transmission of major viral diseases of humans and how defensive chemicals produced by symbionts protect insects from predation. Detailed coverage is given to the elaborate “cross-talk” between microbe and animal needed to establish the squid light organ.

## UNIT 6 Microbe–Human Interactions and the Immune System

### Chapter 24

- A chapter on the human microbiome launches the unit on microbe–human interactions and the immune system by introducing and updating advances in our understanding of the microbes that inhabit the human body and their relationship to health and disease.
- Some highlights: The discovery of ultrasmall bacteria in the mouth parasitizing other bacteria brings a new twist to the microbial ecology of the oral cavity. A new section on the human virome describes how metagenomics is driving the discovery and isolation of interesting new viruses. Extensive coverage is devoted to the impact of early-life events on the development of the newborn gut microbiome and of recent successes in probiotic therapy for preventing newborn intestinal diseases.

### Chapter 25

- Beginning with this chapter, the book shifts its focus to pathogenic microorganisms, the immune system, and disease. Part I of this chapter addresses microbial adherence, colonization and invasion, and pathogenicity, including important sections on virulence and virulence attenuation. Part II highlights key enzymes and toxins produced by microbes that contribute to pathogenesis.

- Some highlights: The updated text includes expanded coverage of bacterial adhesins supported by a new, two-part figure that highlights new discoveries in staphylococcal adherence. Revised coverage of virulence attenuation includes new artwork to show how this principle can be exploited for development of effective vaccines. An updated discussion of botulinum toxins reflects new findings and clearly presents both the neurotoxic mechanism and the surprising clinical utility of these extremely potent substances.

### Chapter 26

- Chapter 26 opens with an overview of the immune system and the body's first-line barriers to infection. This is followed by a brief discussion of hematopoiesis before focusing on innate immune responses to pathogen invasion. The chapter provides a natural progression into adaptive immune responses covered in Chapter 27.
- Some highlights: In addition to a new chapter opener highlighting breakthroughs that link Alzheimer's disease to microbial infection, this chapter contains heavily edited text that includes a more comprehensive discussion of leukocyte diversity and an all-new description of the role of amyloid- $\beta$  protein as an innate defense in the brain. Other highlights include expanded coverage of interferons and the role of natural killer cells as the primary effectors of antibody-dependent cell-mediated cytotoxicity. Finally, a fascinating new Explore the Microbial World highlights the role of pattern recognition receptors in establishing host-microbe mutualisms using hydrothermal vent tube worms as an example.

### Chapter 27

- Chapter 27 begins with an essential discussion of the principles that define adaptive immunity: specificity, immune memory, lymphocyte selection, and immune tolerance. This is followed by sections that discuss the functional mechanisms of the key cells and proteins (immunoglobulins, major histocompatibility complexes, and T cell receptors) that drive adaptive immunity.
- Some highlights: The text has been heavily edited throughout, and this has produced a clearer and more informative presentation of B and T lymphocyte selection and tolerance, including a new discussion of T-dependent versus T-independent antigens. In addition, a new section dedicated to T cell activation and anergy clearly presents the important concept of the second signal required for T cell activation.

### Chapter 28

- The newly reorganized Chapters 28 and 29 have emerged from materials presented in Chapter 28 of the 15th edition. Treating immune disorders and antimicrobial therapy (Chapter 28) separately from clinical diagnostic methods (Chapter 29) has produced a more teachable format, making these topics more accessible for students and easier for the instructor to plan course assignments.
- Some highlights: The text progresses smoothly from immune disorders and deficiencies to methods used to train and hone the immune response for disease prevention and treatment. New coverage of mRNA and plant-based vaccines shares the latest innovations in vaccinology. An all-new section on immunotherapy, supported by vibrant new artwork, highlights exciting advancements in the use of genetic engineering and molecular immunology to treat cancer.

## UNIT 7 Infectious Diseases

### Chapter 29

- To bring better focus to the material, this chapter is now solely dedicated to the clinical microbiology laboratory and includes information on lab safety, healthcare-associated infections, and a wide array of both culture-dependent and culture-independent techniques used to diagnose infectious diseases.
- Some highlights: The chapter launches with the description of an exciting new method of diagnosing tuberculosis—humanity's most notorious scourge. The text has been edited throughout for better organization and clarity, and art modifications help clarify complex diagnostic techniques. Updated terminology includes an introduction to point-of-care diagnostics.

### Chapter 30

- This chapter introduces the topics and terminology of the science of epidemiology and public health. Historical and modern examples throughout emphasize key concepts such as emerging (and reemerging) diseases, epidemics and pandemics, and the public health threat associated with the development and use of weaponized microorganisms.
- Some highlights: incorporation of the most up-to-date statistics available on disease incidence and outbreaks throughout the text and in figures and tables, as well as an all-new section supported by photos on the emergence of the important healthcare-associated pathogen *Clostridioides (Clostridium) difficile*.

### Chapter 31

- This is the first of four highly visual chapters that take an ecological approach to pathogenic microorganisms by considering infectious diseases based on their modes of transmission. Bacterial and viral diseases transmitted person to person by way of airborne particles, direct contact, or sexual contact are the focus here.
- Some highlights: Statistical data regarding key emerging and reemerging diseases, including measles, pertussis, influenza, hepatitis, HIV/AIDS, gonorrhea, and syphilis have been updated to reflect the most recent data available; an all-new discussion with supporting photo of the neglected tropical disease yaws helps impart knowledge and awareness of this lingering scourge.

### Chapter 32

- In this chapter we examine pathogens transmitted to humans through either an animal vector or soil-contaminated wounds or objects. Many of these diseases have high morbidity and mortality rates, and in most cases, effective vaccines are not yet available.
- Some highlights: The text and figures include the most up-to-date statistics for diseases throughout the chapter, including rabies, hantavirus, spotted fever rickettsiosis, ehrlichiosis and anaplasmosis, Lyme disease, and the major tropical hemorrhagic fevers. In addition, the text now includes updated discussions of the emergence of key tickborne diseases in the United States and coverage of new strategies against dengue fever, including description of a new vaccine and the use of the bacterial endosymbiont *Wolbachia* to control the dengue virus-infected mosquito population.

### Chapter 33

- Pathogens in contaminated water or food are easily transmitted to humans, with waterborne diseases being especially common in developing countries lacking adequate water treatment facilities. This chapter highlights the most prevalent water- and foodborne diseases and emphasizes the importance of clean water and proper food preparation and preservation in preventing these physically uncomfortable and occasionally fatal illnesses.
- Some highlights: Updated statistics have been incorporated for all major water- and foodborne diseases, including *Campylobacter* infections, which have now overtaken salmonellosis as the leading cause of bacterial food infection in the United States. New discussions cover recently elucidated norovirus pathology and new food safety developments, including the use of eBeam technology and bacteriophage sprays. A new overview figure of cholera infection integrates photos with artwork to emphasize key aspects of this devastating and all too common disease.

### Chapter 34

- Eukaryotic pathogens present a special challenge to medicine because, on a cellular level, they are not that different from our own cells. Thus, it can be difficult to find selective targets for chemotherapeutic drugs. Yet the microbes highlighted in this highly visual chapter cause some of the most devastating and prevalent diseases today.
- Some highlights: New color photos adorn the chapter, including two stunning fluorescent micrographs of *Entamoeba histolytica*, the causative agent of amebic dysentery. Broader coverage of distinctive features of several diseases, including cyclosporiasis, toxoplasmosis, and malaria, has been seamlessly incorporated. All statistics have been updated with the most recent surveillance data to yield a global picture of fungal and parasitic diseases.