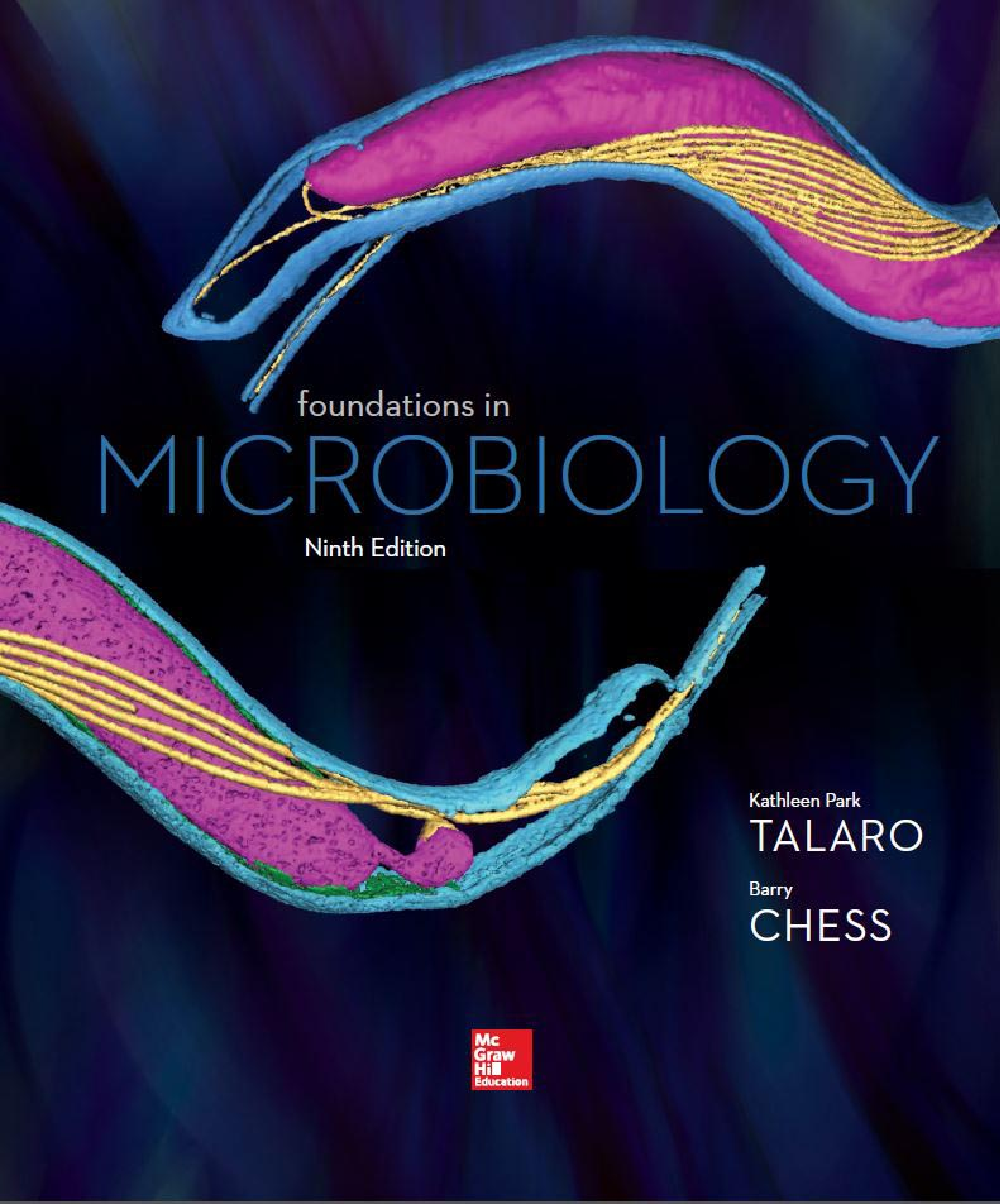

foundations in

MICROBIOLOGY

Ninth Edition

Kathleen Park
TALARO

Barry
CHESS

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Education

FOUNDATIONS IN MICROBIOLOGY, NINTH EDITION

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Brief Contents

About the Authors

Kathleen Park Talaro is a microbiologist, educator, author, and artist. She has been nurturing her love of microbiology since her youth growing up on an Idaho farm where she was first fascinated by tiny creatures she could just barely see swimming in a pond. This interest in the microbial world led to a biology major at Idaho State University, where she worked as a teaching assistant and scientific illustrator for one of her professors. This was the beginning of an avocation that she continues today—that of lending her artistic hand to interpretation of scientific concepts. She continued her education at Arizona State University, Occidental College, California Institute of Technology, and California State University.

She has taught microbiology and major's biology courses at Pasadena City College for 30 years, during which time she developed new curricula and refined laboratory experiments. She has been an author of, and contributor to, several publications of the William C. Brown Company and McGraw-Hill Publishers since the early 1980s, first illustrating and writing for laboratory manuals and later developing this textbook. She has also served as a coauthor with Kelly Cowan on the first two editions of *Microbiology: A Systems Approach*.

Kathy continues to make microbiology a major focus of her life and is passionate about conveying the significance and practical knowledge of the subject to students, colleagues, family, friends, and practically anyone who shows interest. In addition to her writing and illustration, she keeps current attending conferences and participating in the American Society for Microbiology and its undergraduate educational programs. She is gratified by the many supportive notes and letters she has received over the years from devotees of microbiology and users of her book.

She lives in Altadena, California, with husband Dave Bedrosian, and son David. Whenever she can, she visits her family in Idaho. In her spare time, she enjoys photography, reading true crime books, music, crossword puzzles, and playing with her rescued kitties.

A major intent of this textbook has always been to promote an understanding of microbes and their intimate involvement in the lives of humans, but we have also aimed to stimulate an appreciation that goes far beyond that. We want you to be awed by these tiniest creatures and the tremendous impact they have on all of the earth's natural activities. We hope you are inspired enough to embrace that knowledge throughout your lives. Happy reading!

About the Authors

Barry Chess has been teaching microbiology at Pasadena City College for over 15 years. He received his Bachelor's and Master's degrees from California State University, Los Angeles, and did several years of postgraduate work at the University of California, Irvine, where his research focused on the expression of eukaryotic genes involved in the development of muscle and bone.

At Pasadena City College, Barry developed a new course in human genetics and helped to institute a biotechnology program. He regularly teaches courses in microbiology, general biology, and genetics, and works with students completing independent research projects in biology and microbiology. Over the past several years, Barry's interests have begun to focus on innovative methods of teaching that lead to greater student understanding. He has written cases for the National Center for Case Study Teaching in Science and presented talks at national meetings on the use of case studies in the classroom. In 2009, his laboratory manual, Laboratory Applications in Microbiology: A Case Study Approach, was published. He is thrilled and feels very fortunate to be collaborating with Kathy Talaro, with whom he has worked in the classroom for more than a decade, on this ninth edition. Barry is a member of the American Society for Microbiology and regularly attends meetings in his fields of interest, both to keep current of changes in the discipline and to exchange teaching and learning strategies with others in the field.

With this ninth edition, digital author **Heidi Smith** continues the journey of transformation into the digital era with us. Heidi Smith is the lead faculty for microbiology at Front Range Community College in Fort Collins, CO and teaches a variety of biology courses each semester including microbiology, anatomy/physiology, and biotechnology. Heidi has also served as the director of the Honors Program at the college for five years, working with a group of faculty to build the program from the ground up.

Student success is a strategic priority at FRCC and a personal passion of Heidi's, and she continually works to develop professionally in ways that help her do a better job of reaching this important goal. Throughout the past few years, Heidi has had the opportunity to collaborate with faculty all over the country in developing digital tools, such as LearnSmart, LearnSmart Labs, and Connect, to facilitate student learning and measure learning outcomes. This collaborative experience and these tools have revolutionized her approach to teaching and dramatically affected student performance in her courses, especially microbiology hybrid courses where content is delivered partially online.

Heidi is an active member of the American Society for Microbiology and has presented instructional technology and best online and face-to-face teaching practices on numerous occasions at the annual conference for undergraduate educators. She also served as a member of the ASM Task Force on Curriculum Guidelines for Undergraduate Microbiology Education, assisting in the identification of core microbiology concepts as a guide to undergraduate instruction.

Integrated and Adaptive Learning Systems

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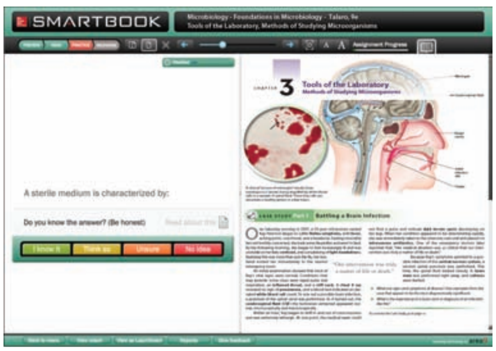

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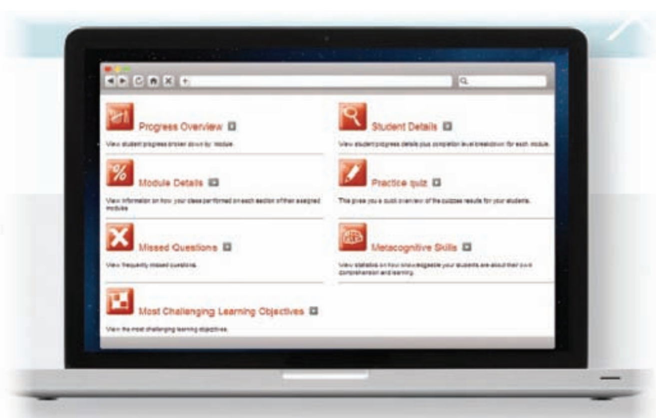

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"I love LearnSmart. Without it, I would not be doing well."
—*student*, Triton College

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LearnSmart is the only adaptive learning program proven to effectively assess a student's knowledge of basic course content and help them master it. By considering both confidence level and responses to actual content questions, LearnSmart identifies what an individual student knows and doesn't know and builds an optimal learning path, so that they spend less time on concepts they already know and more time on those they don't. LearnSmart also predicts when a student will forget concepts and introduces remedial content to prevent this. The result is that LearnSmart's adaptive learning path helps students learn faster, study more efficiently, and retain more knowledge, allowing instructors to focus valuable class time on higher-level concepts.

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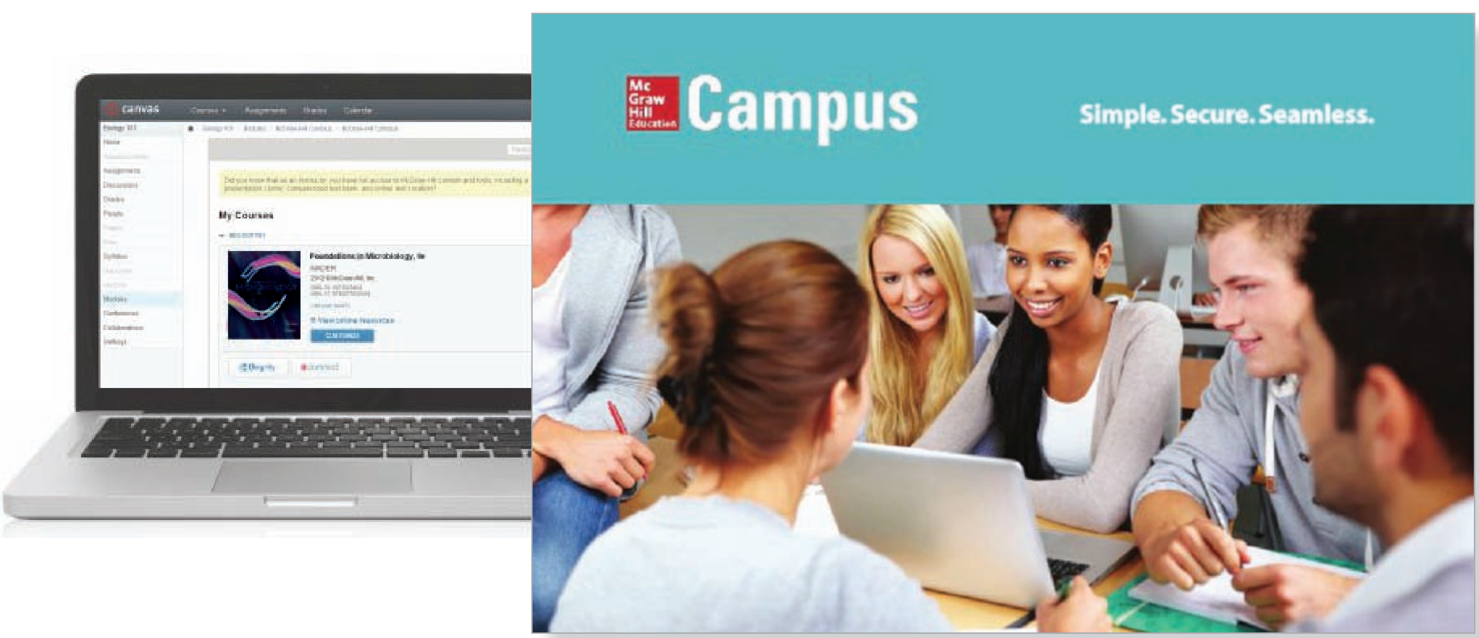

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> "...I and my adjuncts have reduced the time we spend on grading by 90 percent and student test scores have risen, on average, 10 points since we began using Connect!"
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> —*William Hoover,*
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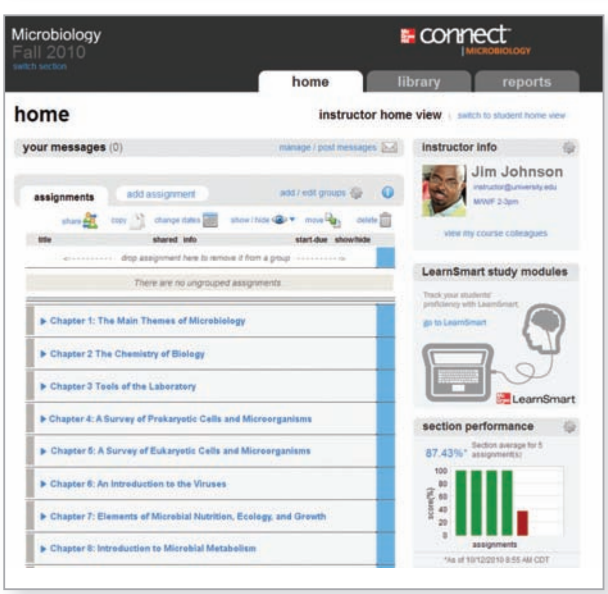

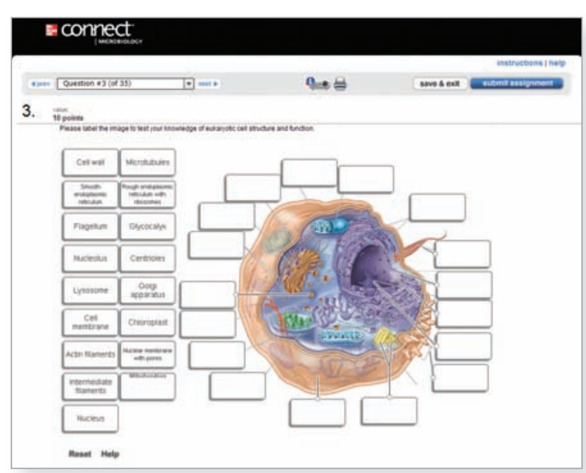

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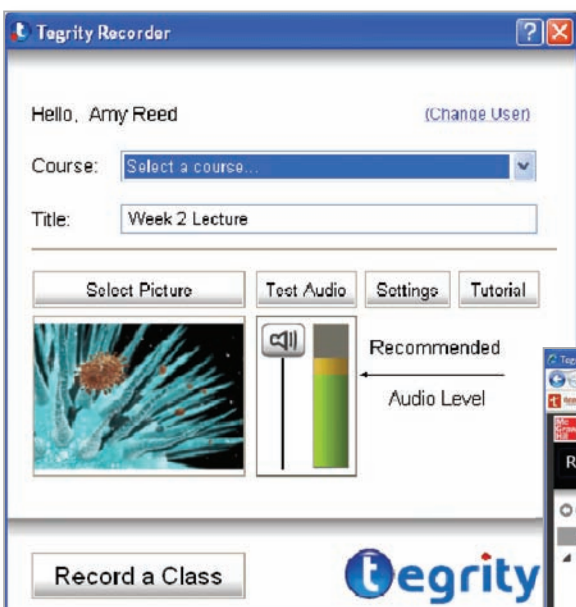

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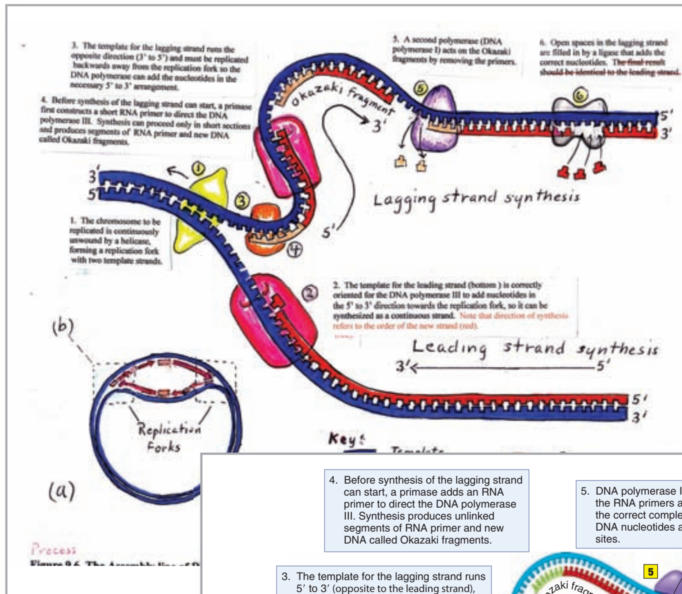
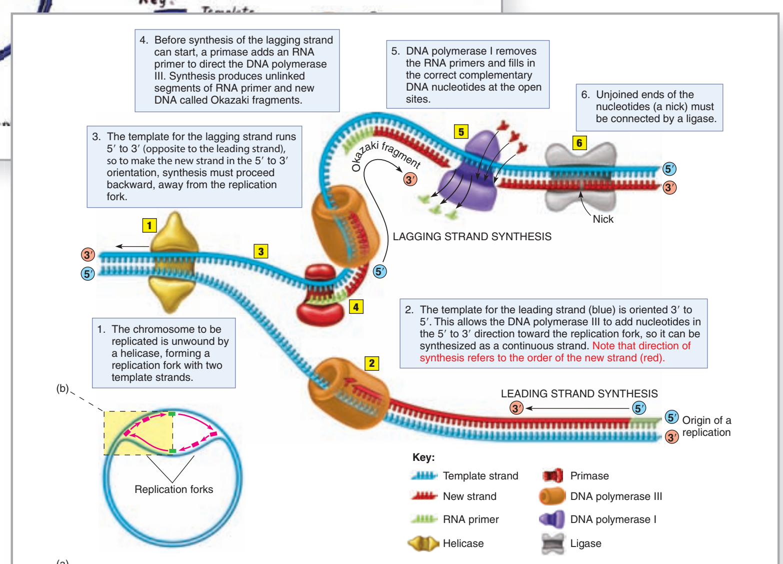
The **Profile** of an Expertly Crafted Learning Tool

Art and organization of content make this book unique

Carefully crafting a textbook to be a truly useful learning tool for students takes time and dedication. Every line of text and every piece of art in this book is scrutinized for instructional usefulness, placement, and pedagogy, and then reexamined with each revision. In this ninth edition, the authors have gone through the book page by page, with more depth than ever before, to make sure it maintains its instructional quality; fantastic art program; relevant and current material; and engaging, user-friendly writing style. Since the first edition, the goals of this book have been to explain complex topics clearly and vividly, and to present the material in a straightforward way that students can understand. The ninth edition continues to meet these goals with the most digitally integrated, up-to-date, and pedagogically important revision yet.





Process Figure 9.6 **The assembly line of DNA replication in a circular bacterial chromosome. (a)** A bacterial chromosome showing the overall pattern of replication. There are two replication forks where new DNA is being synthesized. **(b)** An enlarged view of the left replication fork to show the details of replication.

Like a great masterpiece hanging in a museum, *Foundations in Microbiology* is not only beautiful, but also tells a story, composed of many pieces. A great textbook must be carefully constructed to place art where it makes the most sense in the flow of the narrative; create process figures that break down complex processes into their simplest parts; provide explanations at the correct level for the student audience; and offer pedagogical tools that help all types of learners. Many textbook authors write the narrative of their book and call it a day. It is the rare author team indeed, who examines each page and makes changes based on what will help the students the most, so that when the pieces come together, the result is an expertly crafted learning tool—a story of the microbial world.

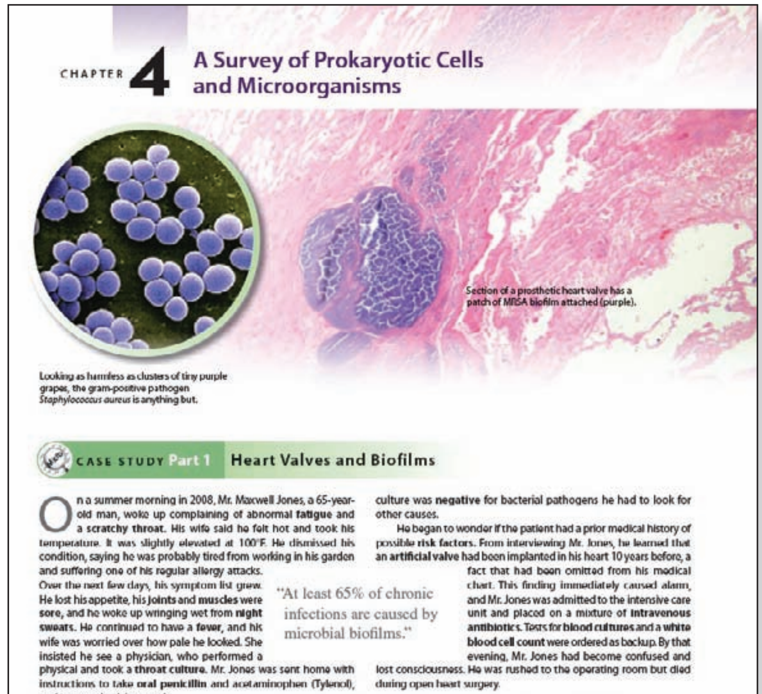
Kathy Talaro introduces new art to a revision by carefully sketching out what she envisions in precise detail, with accompanying instructions to the illustrator. The result is accurate, beautifully rendered art that helps difficult concepts come to life.

> "I would rate this textbook a perfect 10 for readability. The text is clear and there are graphics, stories, and well-organized information that builds in complexity to keep the student informed."
>
> *—Michelle Milner, Otawamba Community College*

The **Structure** of an Expertly Crafted Learning Tool

Chapter Opening Case Studies

Each chapter opens with a Case Study Part 1, which helps the students appreciate and understand how microbiology impacts their lives. Appropriate line art, micrographs, and quotes have been added to the chapter-opening page to help the students pull together the big picture and grasp the relevance of the material they're about to learn. The questions that directly follow Case Studies, Parts 1 and 2 challenge students to begin to think critically about relevant text references that will help them answer the questions as they work through the chapter. The Case Study Perspective wraps up the case and can be found at www.mhhe.com/talaro9, or on the Connect website.


CHAPTER 4 A Survey of Prokaryotic Cells and Microorganisms

Looking as harmless as clusters of tiny purple grapes, the gram-positive pathogen *Staphylococcus aureus* is anything but.

Section of a prosthetic heart valve has a patch of MRSA biofilm attached (purple).

CASE STUDY Part 1 Heart Valves and Biofilms

On a summer morning in 2008, Mr. Maxwell Jones, a 65-year-old man, woke up complaining of abnormal **fatigue** and a **scratchy throat**. His wife said he felt hot and took his temperature. It was slightly elevated at 100°F. He dismissed his condition, saying he was probably tired from working in his garden and suffering one of his regular allergy attacks. Over the next few days, his symptom list grew. He lost his appetite, his **joints** and **muscles** were **sore**, and he woke up wringing wet from **night sweats**. He continued to have a **fever**, and his wife was worried over how pale he looked. She insisted he see a physician, who performed a physical and took a **throat culture**. Mr. Jones was sent home with instructions to take **oral penicillin** and acetaminophen (Tylenol), and to come back in a week.

At the next appointm... had some of the same sy... now he had begun to ha... ...ysician ... When the...

"At least 65% of chronic infections are caused by microbial biofilms."

culture was **negative** for bacterial pathogens he had to look for other causes.

He began to wonder if the patient had a prior medical history of possible **risk factors**. From interviewing Mr. Jones, he learned that an **artificial valve** had been implanted in his heart 10 years before, a fact that had been omitted from his medical chart. This finding immediately caused alarm, and Mr. Jones was admitted to the intensive care unit and placed on a mixture of **intravenous antibiotics**. Tests for **blood cultures** and a **white blood cell count** were ordered as backup. By that evening, Mr. Jones had become confused and lost consciousness. He was rushed to the operating room but died during open heart surgery.

> "I very much enjoyed these case studies in the chapters. I think that these give students examples of how scientists/medical professionals must look at instances of disease and how they occur and are spread. It gives practical application to the subject of microbiology. These can be used to initiate discussions on current events found in the the news/internet and how information is obtained to solve problems of disease outbreaks."
>
> —*Anne Montgomery,* Pikes Peak Community College

> "This approach is captivating. It catches readers' attention the same way people listen to the "news." The authors start from the scenarios to discussions, implications, and practical applications."
>
> —*Lahn Bloodworth,* Florida State College, Jacksonville

CASE STUDY Part 2

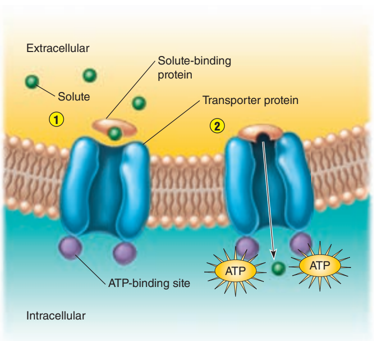
Beginning with those first diagnoses, it took only 6 weeks for the influenza outbreak to explode into a pandemic. New cases quickly appeared in Canada, Central and South America, Europe, Asia, and eventually in more than 200 countries. The CDC's estimates from April to November 2009 suggested that the United States alone accounted for 50 million cases and close to 10,000 deaths. Deaths were particularly high among young children and pregnant women whose treatment had been delayed. Fortunately, the disease experienced by most people was milder than the usual seasonal flu, and it cleared up with few complications. The common symptoms are fever, muscle aches, and problems with breathing and coughing that clear up in 1 or 2 weeks. The most serious complication is pneumonia. One group that seemed to be less susceptible to H1N1 influenza virus were members of the population 60 years or older.

Influenza viruses come in about 144 different subtypes and circulate within many vertebrate groups. As long as the viruses lack the correct spikes for a given host, they cannot jump hosts. But influenza viruses are also notorious for altering the shapes of their spikes so that they can invade more than one host. This has happened several times with bird (avian) flu virus and swine flu viruses. One possible circumstance is when a single animal becomes infected with strains of viruses from two different hosts. The recombination of genes from these viruses can give rise to new viruses with spikes that fit all of the hosts. What evidently happened with the 2009 H1N1 strain is that a small change in a spike was just enough to allow the virus to infect humans.

The **Art** of an Expertly Crafted Learning Tool

Author's experience and talent transforms difficult concepts

Truly instructional artwork has always been a hallmark feature of *Foundations in Microbiology*. Kathy Talaro's experiences as a teacher, microbiologist, and illustrator have given her a unique perspective and the ability to transform abstract concepts into scientifically accurate and educational illustrations. Powerful artwork that paints a conceptual picture for students is more important than ever for today's visual learners. *Foundations in Microbiology's* art program combines vivid colors, multidimensionality, and self-contained narrative to help students study the challenging concepts of microbiology.

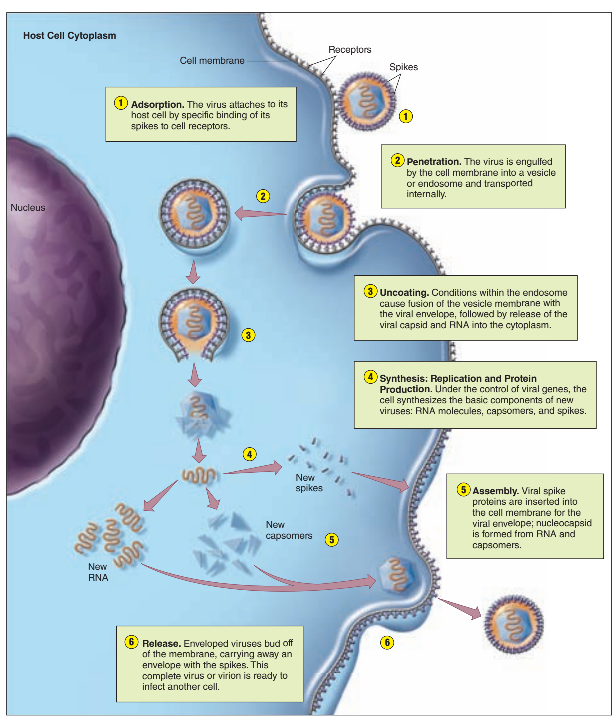


(a) **Carrier-mediated active transport.** (1) Membrane-bound transporter proteins (permeases) interact with nearby solute binding proteins that carry essential solutes (sodium, iron, sugars). (2) Once a binding protein attaches to a specific site, an ATP is activated and generates energy to pump the solute into the cell's interior through a special channel in the permease.

> "Great illustrations, excellent support for the text."
>
> —*Peter Kourtev*, Central Michigan University

Process Figures

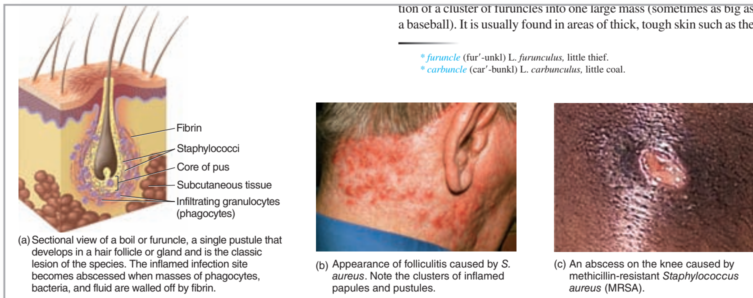
Many difficult microbiological concepts are best portrayed by breaking them down into stages that students will find easy to follow. These process figures show each step clearly marked with a yellow, numbered circle and correlated to accompanying narrative to benefit all types of learners. Process figures are clearly marked next to the figure number. The accompanying legend provides additional explanation.



Process Figure 6.11 **General features in the multiplication cycle of an enveloped animal virus.** Using an RNA virus (rubella virus), the major events are outlined, although other viruses will vary in exact details of the cycle.

The **Relevance** of an Expertly Crafted Learning Tool

Real clinical photos help students visualize



(a) Sectional view of a boil or furuncle, a single pustule that develops in a hair follicle or gland and is the classic lesion of the species. The inflamed infection site becomes abscessed when masses of phagocytes, bacteria, and fluid are walled off by fibrin.

(b) Appearance of folliculitis caused by *S. aureus*. Note the clusters of inflamed papules and pustules.

(c) An abscess on the knee caused by methicillin-resistant *Staphylococcus aureus* (MRSA).

Figure 18.3 **Cutaneous lesions of *Staphylococcus aureus*.** Fundamentally, all are skin abscesses that vary in size, depth, and degree of tissue involvement.

Clinical Photos

Color photos of individuals affected by disease provide students with a real-life, clinical view of how microorganisms manifest themselves in the human body.

Figure 19.22 **Deformation of the hands caused by borderline leprosy.** The clawing and wasting are chiefly due to nerve damage that interferes with musculoskeletal activity. Individuals in a later phase of the disease can lose their fingers.

> "My overall impression is that the text is well organized, thorough without being overwhelming, visually appealing (fonts, illustrations, colors, etc.), accurate and interesting."
>
> —*Kim Raun,* Wharton County Junior College

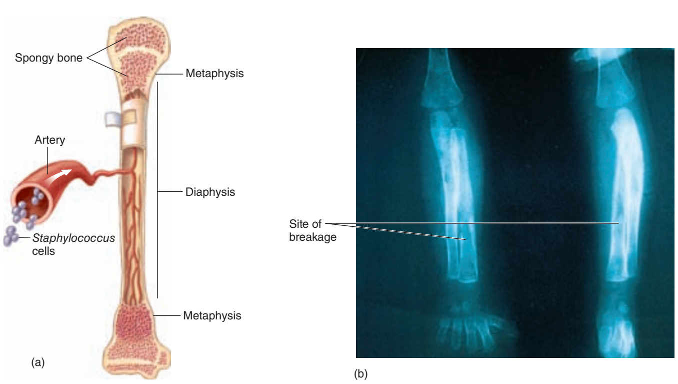
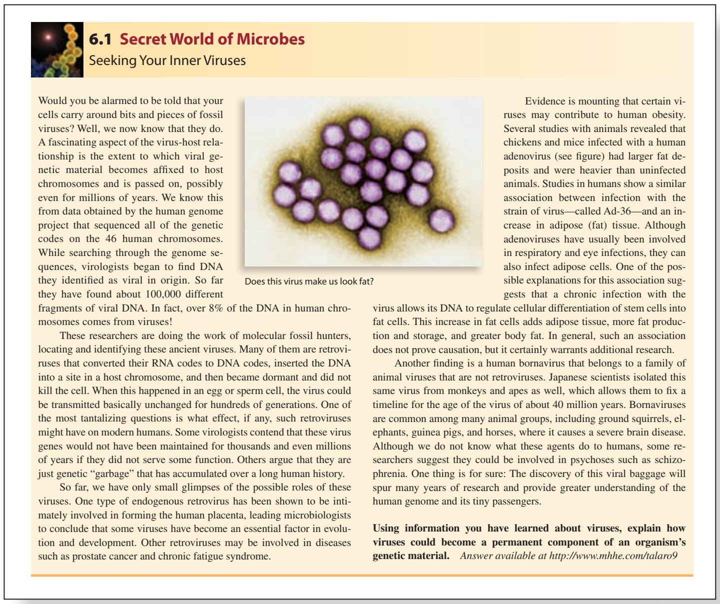


Figure 18.4 **Staphylococcal osteomyelitis in a long bone.** **(a)** In the most common form, the bacteria spread in the circulation from some other infection site, enter the artery, and lodge in the small vessels in bony pockets of the marrow. Growth of the cells causes inflammation and damage that manifest as swelling and necrosis. **(b)** X-ray view of a ruptured ulna caused by osteomyelitis.

Combination Figures

Line drawings combined with photos give students two perspectives: the realism of photos and the explanatory clarity of illustrations. The authors chose this method of presentation often to help students comprehend difficult concepts.

The **Purpose** of an Expertly Crafted Learning Tool


6.1 Secret World of Microbes
Seeking Your Inner Viruses

Would you be alarmed to be told that your cells carry around bits and pieces of fossil viruses? Well, we now know that they do. A fascinating aspect of the virus-host relationship is the extent to which viral genetic material becomes affixed to host chromosomes and is passed on, possibly even for millions of years. We know this from data obtained by the human genome project that sequenced all of the genetic codes on the 46 human chromosomes. While searching through the genome sequences, virologists began to find DNA they identified as viral in origin. So far they have found about 100,000 different fragments of viral DNA. In fact, over 8% of the DNA in human chromosomes comes from viruses!

These researchers are doing the work of molecular fossil hunters, locating and identifying these ancient viruses. Many of them are retroviruses that converted their RNA codes to DNA codes, inserted the DNA into a site in a host chromosome, and then became dormant and did not kill the cell. When this happened in an egg or sperm cell, the virus could be transmitted basically unchanged for hundreds of generations. One of the most tantalizing questions is what effect, if any, such retroviruses might have on modern humans. Some virologists contend that these virus genes would not have been maintained for thousands and even millions of years if they did not serve some function. Others argue that they are just genetic "garbage" that has accumulated over a long human history.

So far, we have only small glimpses of the possible roles of these viruses. One type of endogenous retrovirus has been shown to be intimately involved in forming the human placenta, leading microbiologists to conclude that some viruses have become an essential factor in evolution and development. Other retroviruses may be involved in diseases such as prostate cancer and chronic fatigue syndrome.

Does this virus make us look fat?

Evidence is mounting that certain viruses may contribute to human obesity. Several studies with animals revealed that chickens and mice infected with a human adenovirus (see figure) had larger fat deposits and were heavier than uninfected animals. Studies in humans show a similar association between infection with the strain of virus—called Ad-36—and an increase in adipose (fat) tissue. Although adenoviruses have usually been involved in respiratory and eye infections, they can also infect adipose cells. One of the possible explanations for this association suggests that a chronic infection with the virus allows its DNA to regulate cellular differentiation of stem cells into fat cells. This increase in fat cells adds adipose tissue, more fat production and storage, and greater body fat. In general, such an association does not prove causation, but it certainly warrants additional research.

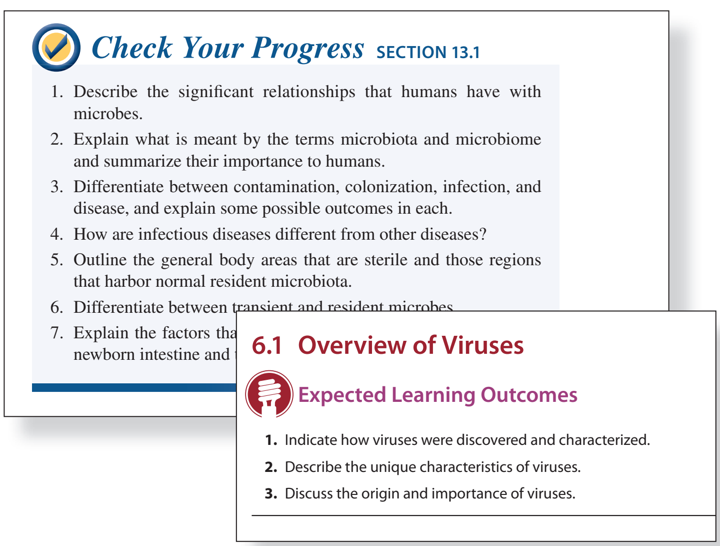
Another finding is a human bornavirus that belongs to a family of animal viruses that are not retroviruses. Japanese scientists isolated this same virus from monkeys and apes as well, which allows them to fix a timeline for the age of the virus of about 40 million years. Bornaviruses are common among many animal groups, including ground squirrels, elephants, guinea pigs, and horses, where it causes a severe brain disease. Although we do not know what these agents do to humans, some researchers suggest they could be involved in psychoses such as schizophrenia. One thing is for sure: The discovery of this viral baggage will spur many years of research and provide greater understanding of the human genome and its tiny passengers.

Using information you have learned about viruses, explain how viruses could become a permanent component of an organism's genetic material. *Answer available at http://www.mhhe.com/talaro9*

NEW! Secret World of Microbes

The living world abounds with incredible, fascinating microbes that have yet to be discovered or completely understood. We have added this new feature to enrich our coverage of the latest research discoveries and applications in the field of microbiology. Almost like reading a mystery novel, *The Secret World of Microbes* reveals little known and surprising facts about this hidden realm.

> "The Insight readings give the student some "gee-golly-whiz" information that they think is just interesting, but is also informative at the same time."
>
> —*Carroll W. Bottoms*, Collin County Community College


Check Your Progress SECTION 13.1

1. Describe the significant relationships that humans have with microbes.
2. Explain what is meant by the terms microbiota and microbiome and summarize their importance to humans.
3. Differentiate between contamination, colonization, infection, and disease, and explain some possible outcomes in each.
4. How are infectious diseases different from other diseases?
5. Outline the general body areas that are sterile and those regions that harbor normal resident microbiota.
6. Differentiate between transient and resident microbes.
7. Explain the factors tha newborn intestine and

6.1 Overview of Viruses

Expected Learning Outcomes

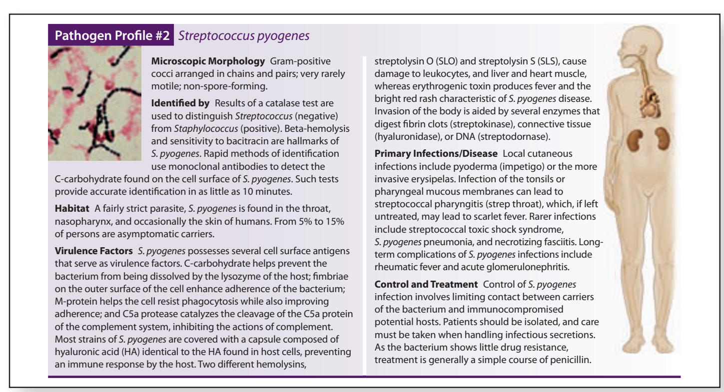
1. Indicate how viruses were discovered and characterized.
2. Describe the unique characteristics of viruses.
3. Discuss the origin and importance of viruses.

Learning Outcomes and Check Your Progress

Every section in the book now opens with Expected Learning Outcomes and closes with assessment questions (Check Your Progress). The Learning Outcomes are tightly correlated to digital material. Instructors can easily measure student learning in relation to the specific learning outcomes used in their course. You can also assign Check Your Progress questions to students through McGraw-Hill ConnectPlus™ Microbiology.

Pathogen Profiles

The eighth edition saw an unveiling of a new feature in the disease chapters called "Pathogen Profiles," which are abbreviated snapshots of the major pathogens in each disease chapter. In the ninth edition the Pathogen Profiles take on a new look. Not only is the pathogen featured in a micrograph, along with a description of the microscopic morphology, identification descriptions, habitat information, and virulence factors, the primary infections/disease, as well as the organs and systems primarily impacted are displayed in new artwork within the profile as well.


Pathogen Profile #2 *Streptococcus pyogenes*

Microscopic Morphology Gram-positive cocci arranged in chains and pairs; very rarely motile; non-spore-forming.

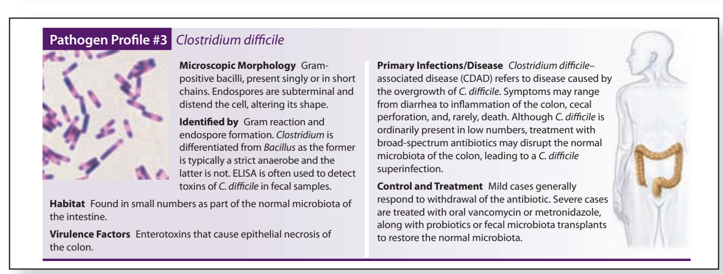
Identified by Results of a catalase test are used to distinguish *Streptococcus* (negative) from *Staphylococcus* (positive). Beta-hemolysis and sensitivity to bacitracin are hallmarks of *S. pyogenes*. Rapid methods of identification use monoclonal antibodies to detect the C-carbohydrate found on the cell surface of *S. pyogenes*. Such tests provide accurate identification in as little as 10 minutes.

Habitat A fairly strict parasite, *S. pyogenes* is found in the throat, nasopharynx, and occasionally the skin of humans. From 5% to 15% of persons are asymptomatic carriers.

Virulence Factors *S. pyogenes* possesses several cell surface antigens that serve as virulence factors. C-carbohydrate helps prevent the bacterium from being dissolved by the lysozyme of the host; fimbriae on the outer surface of the cell enhance adherence of the bacterium; M-protein helps the cell resist phagocytosis while also improving adherence; and C5a protease catalyzes the cleavage of the C5a protein of the complement system, inhibiting the actions of complement. Most strains of *S. pyogenes* are covered with a capsule composed of hyaluronic acid (HA) identical to the HA found in host cells, preventing an immune response by the host. Two different hemolysins, streptolysin O (SLO) and streptolysin S (SLS), cause damage to leukocytes, and liver and heart muscle, whereas erythrogenic toxin produces fever and the bright red rash characteristic of *S. pyogenes* disease. Invasion of the body is aided by several enzymes that digest fibrin clots (streptokinase), connective tissue (hyaluronidase), or DNA (streptodornase).

Primary Infections/Disease Local cutaneous infections include pyoderma (impetigo) or the more invasive erysipelas. Infection of the tonsils or pharyngeal mucous membranes can lead to streptococcal pharyngitis (strep throat), which, if left untreated, may lead to scarlet fever. Rarer infections include streptococcal toxic shock syndrome, *S. pyogenes* pneumonia, and necrotizing fasciitis. Long-term complications of *S. pyogenes* infections include rheumatic fever and acute glomerulonephritis.

Control and Treatment Control of *S. pyogenes* infection involves limiting contact between carriers of the bacterium and immunocompromised potential hosts. Patients should be isolated, and care must be taken when handling infectious secretions. As the bacterium shows little drug resistance, treatment is generally a simple course of penicillin.


Pathogen Profile #3 *Clostridium difficile*

Microscopic Morphology Gram-positive bacilli, present singly or in short chains. Endospores are subterminal and distend the cell, altering its shape.

Identified by Gram reaction and endospore formation. *Clostridium* is differentiated from *Bacillus* as the former is typically a strict anaerobe and the latter is not. ELISA is often used to detect toxins of *C. difficile* in fecal samples.

Habitat Found in small numbers as part of the normal microbiota of the intestine.

Virulence Factors Enterotoxins that cause epithelial necrosis of the colon.

Primary Infections/Disease *Clostridium difficile*–associated disease (CDAD) refers to disease caused by the overgrowth of *C. difficile*. Symptoms may range from diarrhea to inflammation of the colon, cecal perforation, and, rarely, death. Although *C. difficile* is ordinarily present in low numbers, treatment with broad-spectrum antibiotics may disrupt the normal microbiota of the colon, leading to a *C. difficile* superinfection.

Control and Treatment Mild cases generally respond to withdrawal of the antibiotic. Severe cases are treated with oral vancomycin or metronidazole, along with probiotics or fecal microbiota transplants to restore the normal microbiota.

The **Framework** of an Expertly Crafted Learning Tool

Pedagogy created to promote active learning

CLINICAL CONNECTIONS

An Outbreak of Fungal Meningitis

Most fungi are not invasive and do not ordinarily cause serious infections unless a patient's immune system is compromised or the fungus is accidentally introduced into sterile tissues. In 2012, we witnessed how a simple medical procedure could turn into a medical nightmare because a common, mostly harmless fungus got into the wrong place at the wrong time. It all started when a small compounding pharmacy in Massachusetts unknowingly sent out hundreds of mold-contaminated medication vials to medical facilities for injections to control pain. These vials were sent to 23 states and used to inject the drug into the spinal column or joints of around 14,000 patients. By the time any problems were reported, several hundred cases of infection had occurred, half of which settled in the meninges. The most drastic outcome was the deaths of 39 patients from complications of meningitis. After months of investigation, the CDC isolated a black mold, *Exserohilum rostratum*, from both the patients and drug vials.

This mold resides in plants and soil, from which it spreads into the air and many human habitats. But it is not considered a human pathogen, and infections with it are very rare. Examination of the compounding facility uncovered negligence and poor quality control, along with dirty preparation rooms. Mold spores were introduced during filling of the vials, and because the medication lacked preservatives, they survived and grew.

This case drives home several important facts about fungi: (1) They can grow rapidly even in low nutrient environments; (2) just a single spore introduced into a sterile environment, whether it is a vial of medicine or the human body, can easily multiply into millions of fungal cells; and (3) even supposedly "harmless" fungi are often opportunistic, meaning that they will infect tissues "if given an opportunity." This case also emphasizes the need for zero tolerance for microbes of any kind in a drug that is being injected—such a procedure demands sterility. When you think of it, the patients were actually being inoculated in a way that assured the development of serious mycoses.

Explain how a supposedly harmless, airborne mold could get all the way into the brain and cause meningitis. *Answer available at http://www.mhhe.com/talaro9*

Clinical Connections

Found throughout each chapter, current, real-world readings allow students to fit together the interconnections between, microbe, classification, cause and effect, and treatment, just like pieces of a puzzle.

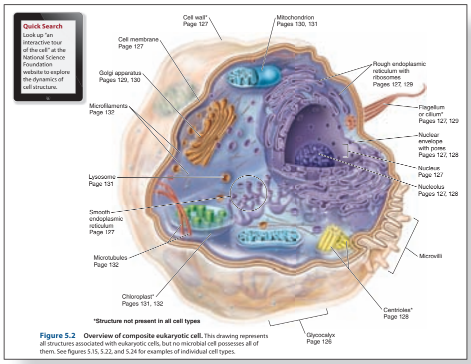


Figure 5.2 **Overview of composite eukaryotic cell.** This drawing represents all structures associated with eukaryotic cells, but no microbial cell possesses all of them. See figures 5.15, 5.22, and 5.24 for examples of individual cell types.

Quick Search

This new feature reminds students that videos, animation, and pictorial displays that provide further information on the topic are just a "click" away using their smart-phone, tablet, or computer. This integration of learning via technology assists students to become more engaged and empowered in their study of the featured topic.

Tables

This edition contains numerous illustrated tables. Horizontal contrasting lines set off each entry, making them easy to read.

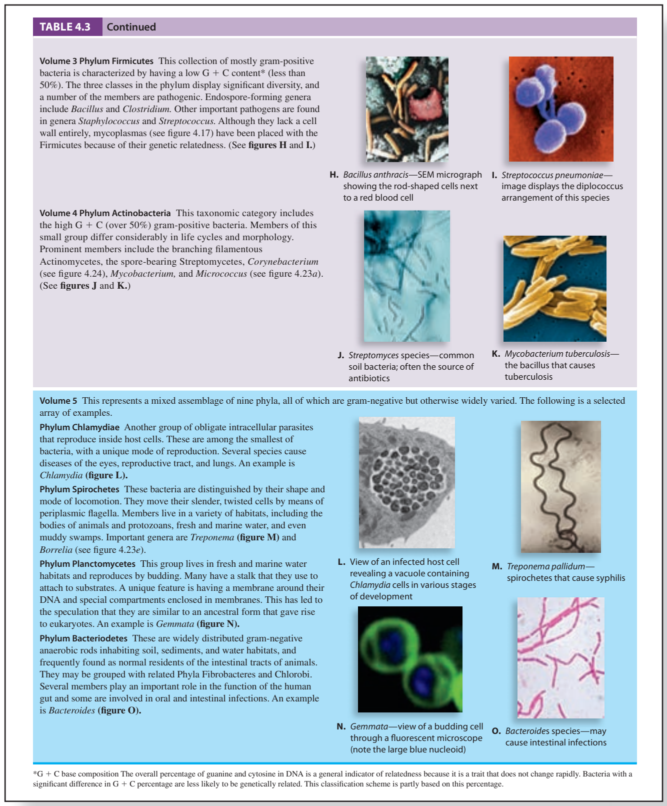


TABLE 4.3 Continued

Volume 3 Phylum Firmicutes This collection of mostly gram-positive bacteria is characterized by having a low G + C content* (less than 50%). The three classes in the phylum display significant diversity, and a number of the members are pathogenic. Endospore-forming genera include *Bacillus* and *Clostridium.* Other important pathogens are found in genera *Staphylococcus* and *Streptococcus.* Although they lack a cell wall entirely, mycoplasmas (see figure 4.17) have been placed with the Firmicutes because of their genetic relatedness. (See **figures H** and **I.**)

H. *Bacillus anthracis*—SEM micrograph showing the rod-shaped cells next to a red blood cell

I. *Streptococcus pneumoniae*—image displays the diplococcus arrangement of this species

Volume 4 Phylum Actinobacteria This taxonomic category includes the high G + C (over 50%) gram-positive bacteria. Members of this small group differ considerably in life cycles and morphology. Prominent members include the branching filamentous Actinomycetes, the spore-bearing Streptomycetes, *Corynebacterium* (see figure 4.24), *Mycobacterium,* and *Micrococcus* (see figure 4.23*a*). (See **figures J** and **K.**)

J. *Streptomyces* species—common soil bacteria; often the source of antibiotics

K. *Mycobacterium tuberculosis*—the bacillus that causes tuberculosis

Volume 5 This represents a mixed assemblage of nine phyla, all of which are gram-negative but otherwise widely varied. The following is a selected array of examples.

Phylum Chlamydiae Another group of obligate intracellular parasites that reproduce inside host cells. These are among the smallest of bacteria, with a unique mode of reproduction. Several species cause diseases of the eyes, reproductive tract, and lungs. An example is *Chlamydia* **(figure L).**

Phylum Spirochetes These bacteria are distinguished by their shape and mode of locomotion. They move their slender, twisted cells by means of periplasmic flagella. Members live in a variety of habitats, including the bodies of animals and protozoans, fresh and marine water, and even muddy swamps. Important genera are *Treponema* **(figure M)** and *Borrelia* (see figure 4.23*e*).

Phylum Planctomycetes This group lives in fresh and marine water habitats and reproduces by budding. Many have a stalk that they use to attach to substrates. A unique feature is having a membrane around their DNA and special compartments enclosed in membranes. This has led to the speculation that they are similar to an ancestral form that gave rise to eukaryotes. An example is *Gemmata* **(figure N).**

Phylum Bacteriodetes These are widely distributed gram-negative anaerobic rods inhabiting soil, sediments, and water habitats, and frequently found as normal residents of the intestinal tracts of animals. They may be grouped with related Phyla Fibrobacteres and Chlorobi. Several members play an important role in the function of the human gut and some are involved in oral and intestinal infections. An example is *Bacteroides* **(figure O).**

L. View of an infected host cell revealing a vacuole containing *Chlamydia* cells in various stages of development

M. *Treponema pallidum*—spirochetes that cause syphilis

N. *Gemmata*—view of a budding cell through a fluorescent microscope (note the large blue nucleoid)

O. *Bacteroides* species—may cause intestinal infections

*G + C base composition The overall percentage of guanine and cytosine in DNA is a general indicator of relatedness because it is a trait that does not change rapidly. Bacteria with a significant difference in G + C percentage are less likely to be genetically related. This classification scheme is partly based on this percentage.

5. A mnemonic device to keep track of this is *LEO* says *GER:* *L*ose *E*lectrons *O*xidized; *G*ain *E*lectrons *R*educed.

Footnotes

Footnotes provide the reader with additional information about the text content.

The **Planning** of an Expertly Crafted Learning Tool

Pedagogy designed for varied learning styles

The end-of-chapter material for the ninth edition has been carefully planned and updated to promote active learning and provide review for different learning styles and levels of Bloom's Taxonomy. Questions are now divided into two levels:

Level I. Knowledge and Comprehension; and
Level II. Application, Analysis, Evaluation, and Synthesis.

The consistent layout of each chapter allows students to develop a learning strategy and gain confidence in their ability to master the concepts, leading to success in the class!

Chapter Summary with Key Terms

A brief outline of the main chapter concepts is provided for students with important terms highlighted. Key terms are also included in the glossary at the end of the book.

Chapter Summary with Key Terms

5.1 The History of Eukaryotes

5.2 and 5.3 Form and Function of the Eukaryotic Cell: External and Internal Structures

A. Eukaryotic cells are complex and compartmentalized into individual organelles.
B. Major organelles and other structural features include: appendages (cilia, flagella), **glycocalyx,** cell wall, cytoplasmic (or cell) membrane, **organelles** (nucleus, **nucleolus, endoplasmic reticulum, Golgi complex, mitochondria, chloroplasts),** ribosomes, **cytoskeleton (microfilaments, microtubules).**

5.4 Eukaryotic-Prokaryotic Comparisons and Taxonomy of Eukaryotes

A. The eukaryotic cell can be compared with the prokaryotic cell in structure, size, metabolism, motility, and shape.
B. Taxonomic groups of the Domain Eukarya are based on level of organization, body plan, cell structure, nutrition, metabolism, and certain genetic characteristics.

5.5 The Kingdom of the Fungi

Common names of the macroscopic fungi are mushrooms,

New! Case Study Review

These questions provide a quick check of concepts covered by the Case Study and allow instructors to assess students on the case study material.

Case Study Review

1. Which of these is/are an example(s) of neglected tropical protozoan diseases?
   a. hookworm
   b. Chagas disease
   c. leishmaniasis
   d. a and b
   e. b and c
   f. all of these

Writing Challenge

These questions are suggested as a writing experience. Students are asked to compose a one- or two-paragraph response using the factual information learned in the chapter.

Writing Challenge

For each question, compose a one- or two-paragraph answer that include
Check Your Progress questions can also be used for writing-challenge ex

1. Describe the anatomy and functions of each of the major euka organelles.
2. Trace the synthesis of cell products, their processing, and their packaging through the organelle network.
3. a. What is the reproductive potential of molds in terms of spo production?
   b. How do mold spores differ from bacterial endospores?

Multiple-Choice Questions

Select the correct answer from the answers provided. For questions with blanks, the statement.

1. Both flagella and cilia are found primarily in
   a. algae
   b. protozoa
   c. fungi
   d. both b and c
2. Features of the nuclear envelope include
   a. ribosomes
   b. a double membrane structure
   c. pores that allow communication with the cytoplasm

Multiple-Choice Questions

Students can assess their knowledge of basic concepts by answering these questions and looking up the correct answers in appendix D. In addition, the ConnectPlus eBook allows students to quiz themselves interactively using these questions!

End-of-Chapter Questions

NEW! Questions Are Divided into Two Levels

Level I. Knowledge and Comprehension

These questions require a working knowledge of the conce
and the ability to recall and understand the information yo

Level II. Application, Analysis, Evaluation, and Synthesis

These problems go beyond just restating facts and require higher levels of understanding and an ability to interpret, problem solve, transfer knowledge to new situations, create models, and predict outcomes.

The **Innovation** of an Expertly Crafted Learning Tool

Concept Mapping

Three different types of concept mapping activities are used throughout the text in the end-of-chapter material to help students learn and retain what they've read. Concept Mapping exercises are also now made interactive on ConnectPlus Microbiology!

> "..., THE CONCEPT MAPS ARE EXTREMELY USEFUL AS A MEANS FOR CRITICAL THINKING."
> —*Luis Materon,* University of TX Pan American

Concept Mapping

An Introduction to Concept Mapping found at http://www.mhhe.com/talaro

1. Construct your own concept map using the following words as the *conc*

Golgi apparatus	ribosomes
chloroplasts	flagella
cytoplasm	nucleolus
endoplasmic reticulum	cell membrane

Critical Thinking

Using the facts and concepts they just studied, students must reason and problem solve to answer these specially developed questions. Questions do not have a single correct answer and thus open doors to discussion and application.

Critical Thinking

Critical thinking is the ability to reason and solve problems using facts and concepts. These questions can be approached from a number of angles, and in most cases, they do not have a single correct answer.

1. Explain the ways that mitochondria resemble rickettsias and chloroplasts resemble cyanobacteria.
2. Give the common name of a eukaryotic microbe that is unicellular, walled, nonphotosynthetic, nonmotile, and bud-forming.
3. How are the eukaryotic ribosomes and cell membranes different from those of prokaryotes?
4. What general type of multicellular parasite is composed primarily of thin sacs of reproductive organs?
5. a. Name two parasites that are transmitted in the cyst form.
   b. How must a non-cyst-forming pathogenic protozoan be transmitted? Why?
6. Explain what factors could cause opportunistic mycoses to be a growing medical problem.
7. a. How are bacterial endospores and cysts of protozoa alike?
   b. How do they differ?
8. For what reasons would a eukaryotic cell evolve an endoplasmic reticulum and a Golgi apparatus?
9. Can you think of a simple test to determine if a child is suffering from pinworms? Hint: Clear adhesive tape is involved.

Visual Challenge

1. What term is used to describe a single species exhibiting both cell types shown below, and which types of organisms would most likely have this trait?

Visual Challenge

Visual Challenge questions take images and concepts learned in other chapters and ask students to apply that knowledge to concepts covered in the current chapter.

The **Revision** of an Expertly Crafted Learning Tool

Changes to Foundations in Microbiology, Ninth Edition

Overall Changes:

- This new edition's design incorporates specific icons and headings to highlight each distinct feature, producing a cleaner and less compartmented layout.
- The art program has been rendered in an enhanced, more colorful, and three-dimensional style.
- We added over 120 new or significantly revised figures and 180 new and replacement photographs.
- We added 7 new case studies and updated 10 others with new information.
- Insight boxes have been recast as features titled "Making Connections", "Secret World of Microbes", and "Clinical Connections." Several of these boxes are new to this edition and many have been rewritten or updated.
- We converted the "Take Notes" concepts and set them as regular text under their own headings.
- To integrate information from Internet sites, we placed "Quick Search" motifs within the chapters that direct readers to interesting enrichment topics, videos, or animations that can be quickly accessed with a computer, smart phone, or tablet.
- We developed several new illustrated tables to consolidate information and provide a comparative analysis of concepts such as microscopy, taxonomy, and symbiosis.
- We revised the pedagogy of the end-of-chapter material, which now includes two major levels of questions and review assessments, based on Elements of Bloom's Taxonomy. Level I, titled *Knowledge and Comprehension,* is designed to assess recall and understanding; and Level II, titled *Application, Analysis, Evaluation, and Synthesis,* requires skills in interpretation, problem solving, critical thinking, and creativity.
- The Check and Assess modules at the ends of each section have been changed to "Check Your Progress" questions to focus attention on retaining key information covered in that section.
- Questions throughout the chapters have been modified and compressed; new questions have been written for the Case Study Reviews.
- For the chapters on pathogens 18–25, we created Systems Profiles tables that correlate important species with the major body systems they infect. These will replace the Appendix D tables from previous editions and will provide a compact overview of pathogens and target organs.
- An illustration of the organs and systems that are affected by a pathogen has been added to each Pathogen Profile; additional Pathogens Profiles have been added to several chapters.
- Case Files have been changed to Case Studies. Their presentation has been reorganized, with Part 1 appearing as the chapter opener and Part 2 placed at the end of the chapter before the summary. Part 3, Perspectives, has been moved to the Connect website.
- Addition of color blocking for improving readability and separation of figure components.

Chapter-Specific Changes:

Chapter 1

- Redesigned microbial size and measurement figure, with new images
- A reconfigured table covering the fields in microbiology with new photographs and examples
- A chart mapping emerging and reemerging diseases added to the box on emerging diseases
- A new figure to illustrate applications of the scientific method using vaccination as a topic
- A new figure and table showing disease statistics to replace the original ones
- Simplified charts of two alternate methods of presenting the taxonomy of organisms
- Original taxonomic trees have been refreshed; photographs of examples of major groups were added to the Domain-based tree

Chapter 2

- The figure of atoms was enhanced to look more dynamic and closer to its real structure.
- Developed a box dealing with nanotechnology and drug delivery systems
- Steamlined tables for the characteristics of elements and amino acids
- Improved consistency and color-coding of atoms and molecules

Chapter 3

- New integrated microscope structure/light pathway figure
- New figure comparing resolvable and nonresolvable microorganisms
- Added a Clinical Connections feature on fluorescent microscopy
- A full page illustrated table comparing microscope types and features
- Additional examples of microbiological staining
- New figure comparing types of media and new media images

Chapter 4

- New figure summarizing characteristics of life
- Three Clinical Connections features on bacterial structures that play an important role in infections
- Revised biofilm figure and box
- Revised figure of cell membrane
- New taxonomy tree with emphasis on prokaryotes
- Expanded illustrated tables of major prokaryotic groups
- New *Myxobacterium* life cycle
- Expanded text coverage of Archaea

Chapter 5

- Revised figure and text for nucleus, rough endoplasmic reticulum, smooth endoplasmic reticulum, and Golgi apparatus
- Revised phagocytosis and cytoskeleton figures
- Clinical Connections featuring fungal meningitis
- New figures of sexual reproduction cycle in Zygomycota and Basidiomycota
- Two new illustrated taxonomy tables for fungi and protozoa

Chapter 6

- Added images and discussion of new giant viruses
- Revised figures of virus multiplication cycles
- Revised figures showing virus penetration
- Clinical Connections covering persistent virus infections
- Updated box with material on the connection between obesity and viral infection
- New figure depicting infection mechanisms of prions

Chapter 7

- New figures for osmosis, facilitated diffusion, and active transport
- Temperature figure now includes hyperthermophiles
- Revised section on coevolution and interrelationships
- Figure that defines, classifies, and compares microbial interrelationships using text and images
- Revised figure for spectrophotometry
- New figure and text featuring technology and uses of flow cytometry

The **Effort** of an Expertly Crafted Learning Tool

Chapter 8

- New Case Study dealing with an outbreak of botulism in a prison
- Revised two figures on enzyme-substrate reactions
- New ribozyme figure showing action of ribozyme
- Improved currency and accuracy of section on the electron transport system
- New figure for oxidative phosphorylation and the proton motive force
- Revision on text coverage of photosynthesis
- New figure for the light-dependent reactions
- New figure for the light-independent reactions

Chapter 9

- New figures of DNA and mRNA structure
- Revised text and figures on operons to improve accuracy and readability
- Revised box on regulatory, noncoding RNA, with figure of riboswitches
- Added a multiwell Ames test for detecting mutagens
- Improved consistency of figures for conjugation and transduction

Chapter 10

- New Case Study on the use of genomic medicine for diagnosing diseases
- New figure of electrophoresis technique
- New figure of fluorescent in-situ hybridization
- Updated box on the human genome with a new figure of SNPs
- Revised tables on genetically-engineered plants and animals
- Clinical Connections written for gene therapy
- New microarray figure showcasing the technology involved

Chapter 11

- Updated Case Study on the outbreak of hepatitis C
- Reorganization of figure 11.1 outlining the major types of microbial control
- New photos for tables covering the applications of physical and chemical agents
- New figure of a NASA clean room where space vehicles are constructed

Chapter 12

- New table on drug spectrum of action
- Revised table on modes of action
- Revised table on mechanisms of antiviral drugs
- New table organizing anti-HIV drugs
- Updated drug resistance box and figures
- New figure of MIC tube dilution

Chapter 13

- Box and figure on human microbiome
- New figure outlining the course of an infection
- Reorganized sections to place all epidemiology-related topics together
- New surveillance figures for HIV infection, pertussis, and tuberculosis
- New figures to compare types of epidemics

Chapter 14

- New figure to illustrate surveillance, recognition, and other immune functions
- Improved figure for blood cell development; images of blood cells inserted next to their descriptions
- Improved figure of the stages of inflammation
- Clinical Connections feature dealing with inflammation
- Improved figure of the complement system

Chapter 15

- Added CD receptors to T-cell figure
- Coordinated figure of interactions between APC, T cell, and B cell across two pages; cell art improved
- New three-dimensional model of antibody
- Improved antigen-antibody binding figure
- Additional details added to figure on T-cell activation and function
- New figure of NK cell function
- Added description of T regulatory cells
- Improved figure of vaccine antigens
- Revised list of currently-approved vaccines

Chapter 16

- Reorganized figure of immune diseases
- Revised figure of mechanisms of type I allergies
- New photograph of skin testing
- New photograph of contact dermatitis test
- Updated autoimmunity descriptions
- Improved art for mechanism of type IV hypersensitivity
- Improved art for immunodeficiency diseases

Chapter 17

- New box on advances in laboratory technology and point of care testing
- Added PNA-FISH figure
- New example for polymerase chain reaction test
- New examples of serological test results
- Revamped figure of virus identification

Chapter 18

- New Case Study concerning outbreak of meningitis in an Oklahoma school district
- Updated statistics on the prevalence of diseases attributable to coccus-shaped bacteria
- Tables throughout the chapter rewritten to emphasize the shape and Gram reaction of pathogens.
- Increased information on serological and biochemical tests for rapid detection of Staphylococcal species
- Updated information on treatment of drug resistant staphylococcal and streptococcal infections
- New Pathogen Profiles for *Streptococcus pneumoniae* and *Neisseria meningitidis*
- Text reflects new CDC recommendations for treatment of *Neisseria gonorrhoeae*
- Information concerning *Acinetobacter baumannii* now appears in chapter 18 as a result of recent phylogenetic studies

Chapter 19

- Updated statistics on the prevalence of diseases attributable to gram-positive bacillus shaped bacteria
- Tables throughout chapter have been rewritten to emphasize the shape and Gram reaction of pathogens
- Updated information on recent approval of monoclonal antibodies to treat anthrax
- New information on 2011 listeriosis outbreak linked to cantaloupe
- Updated information on treatment of *Listeria monocytogenes*
- Current recommendations for treatment of drug resistant *Clostridium perfringens* infection, as well as fecal transplant for *Clostridium difficile*
- Streamlined discussion of *Mycobacterium tuberculosis* and updated epidemiological information for the disease, including incidence of extensively drug resistant tuberculosis
- Information on recently approved in vitro tests for the diagnosis of tuberculosis
- Updated information on *Mycobacterium lepromotosis* and zoonotic *Mycobacterium leprae* infections

Chapter 20

- New Case Study on current nationwide pertussis epidemic
- Updated statistics on prevalence of diseases attributable to gram-negative bacilli
- System Profiles present major bacillus pathogens in the chapter from a body systems point-of-view
- Tables throughout chapter have been rewritten to emphasize the shape and Gram reaction of pathogens
- Updated information on recommended drugs for treatment of *Pseudomonas* and *Burkholderia* infection
- New CDC vaccine recommendations for pertussis, as well as a feature on various types of vaccines used to provide protection against pertussis, tetanus, and diphtheria
- Updated information on treatment of *Legionella pneumophila, Shigella, Pasturella, and Haemophilus* infections

Chapter 21

- Updated statistics on prevalence of diseases attributable to bacteria discussed in chapter
- New recommendations for treatment of *Treponema, Borrelia, Campylobacter,* and *Mycoplasma* infections
- WHO recommendations for cholera vaccination
- Information on utility of serological testing in diagnosis of *Helicobacter pylori*

Chapter 22

- New Case Study concerning an outbreak of histoplasmosis in a Nebraska day camp
- Updated statistics on the prevalence of mycotic diseases
- System Profiles present fungal pathogens discussed in chapter from a body systems point-of-view
- Updated information on prognosis of blastomycosis
- Updated information on treatment of all mycotic diseases
- New feature exploring outbreak of fungal meningitis attributed to contaminated steroids in 2012
- Inclusion of genus *Exserohilum* as a potential emerging fungal pathogen

Chapter 23

- New Case Study concerning an outbreak of primary amebic meningoencephalitis due to infection with *Naegleria fowleri*
- System Profiles present parasites discussed in the chapter from a body systems point-of-view
- Addition of *Plasmodium ovale* and *Plasmodium knowlesi* as causative agent of malaria
- Treatment of parasitic infections has been updated to reflect most recent drug recommendations
- Updated information on epidemiology of trichomoniasis, trypanosomiasis, malaria, and cryptosporidiosis
- New feature discussing neglected parasitic infections in United States
- Greater emphasis on use of bed nets to both prevent infection with malaria and to reduce the number of infected mosquitoes in areas where malaria is endemic
- Updated epidemiology of helminthic disease and current recommendations for the treating of helminth infection

Chapter 24

- System Profiles present DNA viruses discussed in the chapter from a body systems point-of-view
- Pathogen Profiles now include a figure illustrating the location in the body where each virus commonly infects
- Additional information on smallpox vaccination and progression of the disease
- Additional information on passive immunization to combat varicella-zoster infection
- The use of the polymerase chain reaction as a means of detecting viral DNA
- Text reflects the current view that Epstein-Barr virus and chronic fatigue syndrome are unrelated
- Treatment of viral infections has been updated to reflect the most recent drug recommendations
- Epidemiology of hepatitis A, B, and C reflect most recent information available
- Updated information on HIV and the risk to the fetus from infected mothers
- Updated recommendations for vaccination against hepatitis B and human papillomavirus

Chapter 25

- System Profiles present RNA viruses discussed in the chapter from a body systems point-of-view
- Updated epidemiological statistics for all viral diseases in the chapter
- Vaccine information updated to reflect latest influenza vaccine composition
- New information concerning the response of CDC and WHO to the 2009 H1N1 pandemic
- New information about traditional, inhalable, and intradermal influenza vaccines
- New information on the 2012 hantavirus outbreak in Yosemite National Park
- Updated information about novel viruses: MERS-CoV, Bas-Congo virus, Heartland virus
- Discussion of deep sequencing technology used to identify novel viruses
- Updated treatment information for parainfluenza and measles
- RT-PCR as the preferred diagnostic technique for detection of respiratory syncytial virus
- New and updated information on dengue virus, including the latest diagnostic methods and results of recent vaccine trials
- Updated epidemiological, diagnostic, and treatment information concerning HIV
- New feature on the Berlin patient along with a second case from 2013, the only two people thought to have been cured of HIV
- New information on hepatitis A vaccination

Chapter 26

- New information on extremophiles and geomicrobiology
- New examples of nitrogen-fixing interactions between *Gunnera* plants and *Nostoc*
- New feature on the “Body Farm” Forensic Anthropology Center
- Updated statistics on water testing, treatment, and safety regulations

Chapter 27

- New Case Study examines the 2012 Listeriosis outbreak linked to cantaloupe
- Updated information on purification of drinking water and treatment of wastewater
- New feature on use of *Botrytis cinerea* in wine making
- Updated statistics on food-borne illness
- New information on food preservation using penetrating radiation and bacteriophage treatment of food
- New information concerning rapid detection of bioterrorism agents

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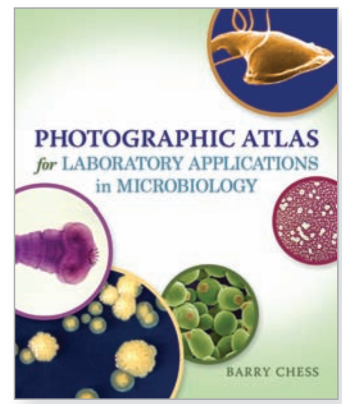

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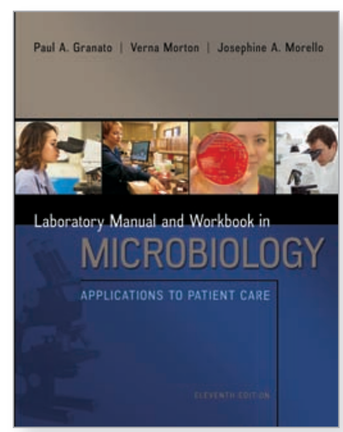

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Acknowledgments

This edition marks the 20th anniversary of the first publication of Foundations in 1993. Looking back over the previous 8 editions, the authors are struck by the extensive discoveries and new developments in the science of microbiology that are reflected in the changing content and character of this book. This 9th edition is no exception. The one thing that has remained constant and unchanging over these years is the outstanding collaboration we enjoy with the editorial and production staff at McGraw-Hill Education. This time around, we have been fortunate to have the able assistance and expertise of developmental editor Mandy Clark, keeping us on track and providing much needed moral support. We also appreciate the insights and contributions of brand manager Amy Reed and marketing manager Patrick Reidy. Our project manager Daryl Bruflodt has been an experienced and knowledgeable guide through the intricacies of a digital-style revision. We value the capable and diligent efforts of Heidi Smith to develop and improve the digital assets for the Connect website.

Other valued members of our team who have been instrumental in developing the text's visual elements are Carrie Burger, the content licensing specialist, Danny Meldung at Photo Affairs, and the designer Tara McDermott, who has produced another striking book and cover design. Some of the unsung heroes of authors are the readers who must sift through the text with a fine-tooth comb, checking for errors, grammatical usage, and consistency in style. This tedious job fell this time to copy editor Bea Sussman and proofreaders Dawnelle Krouse and Judy Gantenbein. After poring over 800 plus pages of text in a few months, they may feel like they've taken a crash course in microbiology.

We rely on the review process to uncover errors, check content, clarify points, and get feedback on accuracy, order, depth, organization, and readability. All of our reviewers provided helpful and constructive suggestions. We are especially indebted to the thorough and careful reviewing by Michael Black of California State Polytechnic Institute, Joe Wolf of Elizabethtown Community and Technical College, Lahn Bloodworth of Florida State College-Jacksonville, Jason Gee of East Carolina University, Mark Farinha of Anne Arundel Community College, Robin Hulbert of California State Polytechnic Institute, and Michelle Milner, Itawamba Community College. As we have pointed out in the past, this book has been a meeting ground for hundreds of contributors over 30 years, whose knowledge and expertise have greatly shaped the end product.

It takes about a year and a half to complete a textbook revision—a process that involves editing manuscript, writing new text, illustration, research, and much more. During this time, the entire text and art program are inspected at least six times by the authors and team members. Even with the keenest eyes and spell checks, some typos, errors, oversights, and other mistakes may end up on the printed page. If you find any of these or wish to make other comments, feel free to contact the publisher, sales representative, or authors (ktalaro@aol.com and bxchess@Pasadena.edu.)

We hope that you enjoy your explorations in the microbial world and that this fascinating science will leave a lasting impression on you.

—Kathy Talaro and Barry Chess

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A Note to the Student

How to Maximize Your Learning Curve

Most of you are probably taking this course as a prerequisite to nursing, dental hygiene, medicine, pharmacy, optometry, physician assistant, or other health science programs. Because you are preparing for professions that involve interactions with patients, you will be concerned with infection control and precautions, which in turn requires you to think about microbes and how to manage them. This means you must not only be knowledgeable about the characteristics of bacteria, viruses, and other microbes; their physiology and primary niches in the world; but you must also have a grasp of disease transmission, the infectious process, disinfection procedures, and drug treatments. You will need to understand how the immune system interacts with microorganisms and the effects of immunization. All of these areas bring their own vocabulary and language—much of it new to you—and mastering it will require time, motivation, and preparation. A valid question students often ask is: "How can I learn this information to increase my success in the course as well as retain it for the future?"

> "This text is the best one on the market to help students understand holistic microbiology concepts and make concrete connections with real world situations."
>
> —*Teresa Wilmoth*, Baker College Port Huron

Right from the first, you need to be guided by how your instructor has organized your course. Since there is more information than could be covered in one semester or quarter, your instructor will select what he/she wants to emphasize and construct a reading and problem assignment that corresponds to lectures and discussion sessions. Many instructors have a detailed syllabus or study guide that directs the class to specific content areas and vocabulary words. Others may have their own website to distribute assignments and even sample exams. Whatever materials are provided, this should be your primary guide in preparing to study.

The next consideration involves your own learning style and what works best for you. To be successful, you must commit essential concepts and terminology to memory. A list of how we retain information called the "pyramid of learning" has been proposed by Edgar Dale: We remember about 10% of what we read; 20% of what we hear; 50% of what we see and hear; 70% of what we discuss with others; 80% of what we experience personally; and 95% of what we teach to someone else.

There are clearly many ways to go about assimilating information—but mainly, you need to become involved in reading, writing, drawing simple diagrams, and discussion or study with others. This means reading alone will not gather the most important points from a chapter. You must attend lecture and laboratory sessions to listen to your instructors or teaching assistants explain the material. Notes taken during lecture can be rewritten or outlined to organize the main points. This begins the process of laying down memory. You should go over concepts with others—perhaps a tutor or study group—and even take on the role of the teacher-presenter part of the time. It is with these kinds of interactions that you will not just rote memorize words but *understand* the ideas and be able to apply them later.

A way to assess your understanding and level of learning is to test yourself. You may use the exam questions in the text, on the Connect website, or make up your own. LearnSmart, available within the Connect site, is an excellent way to map your own, individualized learning program. It tracks what you know and what you don't know and creates questions just for you based on your progress.

Another big factor in learning is the frequency of studying. It is far more effective to spend an hour or so each day for two weeks than a marathon cramming session on one weekend. If you approach the subject in small bites and remain connected with the terminology and topics, over time it will become yours and you will find that the pieces begin to fit together. Just remember that the most effective ways to acquire knowledge are through repetition and experience.

In the final analysis, the process of learning comes down to self-motivation and attitude. There is a big difference between forcing yourself to memorize something to get by and really wanting to know and understand it. Therein is the key to most success and achievement, no matter what your final goals. And though it is true that mastering the subject matter in this textbook requires time and effort, millions of students will affirm how worthwhile it has been in their professions and everyday life.

Contents

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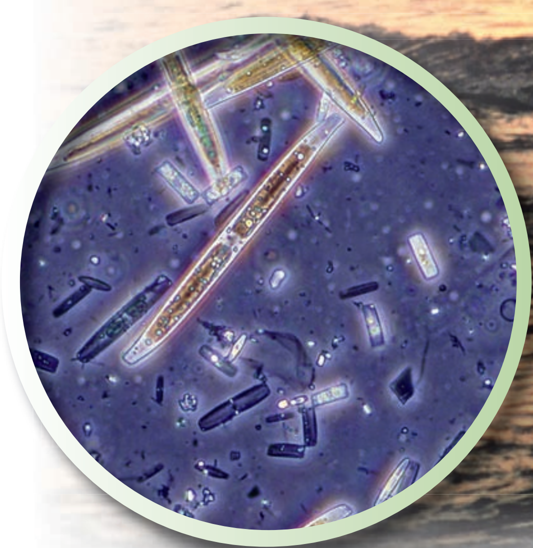
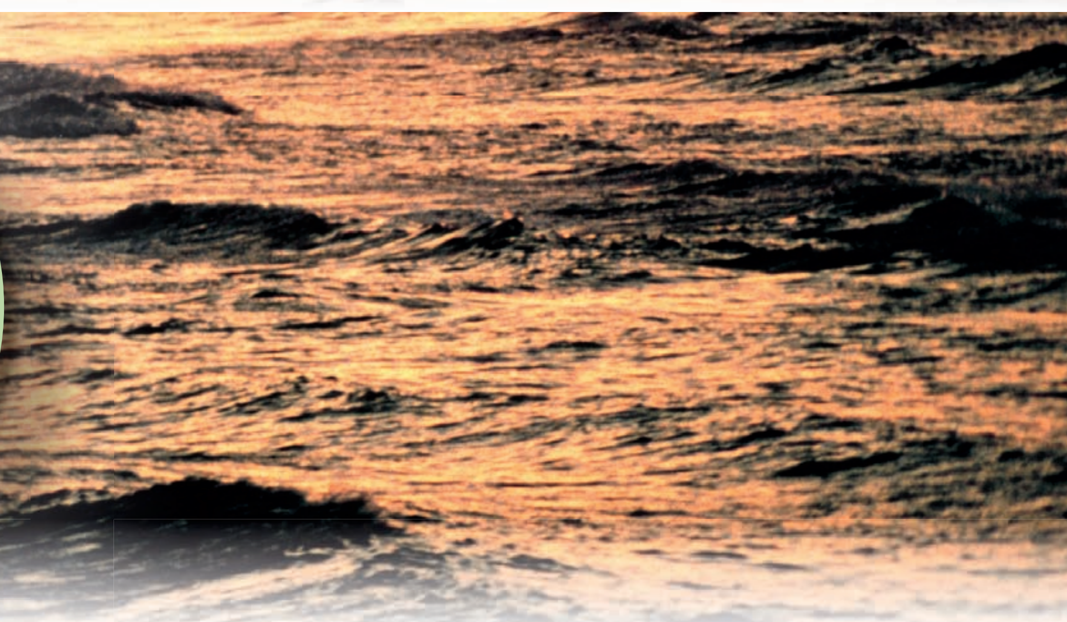
CHAPTER 1

The Main Themes of Microbiology



A plankton sample from the Atlantic Ocean yields up its jewels. The larger gold, white, and blue cells are a type of algae called diatoms, and the tiny white and blue cells are unknown prokaryotes.



A view of the North Atlantic Ocean, a fitting place to mine for marine microbes.

CASE STUDY Part 1 The Search for Biological Dark Matter

From 2002 to 2010, a 100-foot sailboat called the *Sorcerer II* was engaged in a groundbreaking fishing expedition in the oceans of the world. What was highly unusual about this voyage was that it did not involve hooking or netting fish. Instead, the ship was hauling in billions of the tiniest **microorganisms** that float in the upper levels of the marine environment. What researchers aimed to do with their catch was to harness a powerful and very different way to examine the living world.

"Microbes rule the earth."

This project was the brainchild of Dr. Craig Venter, a prominent genetics researcher,* whose goal was to survey the microbial **diversity** of ocean water in more detail than ever before. Scientists aboard the vessel randomly collected surface water about every 200 miles with very fine nets that extracted the **microscopic plankton,** primarily **bacteria,** and sent samples back to Venter's laboratory. Instead of painstakingly isolating and identifying the individual microbes in the sample, as might have been done in the past, they extracted the **genetic material (DNA)** from the samples and analyzed the DNA using state-of-the-art molecular techniques and computers.** When results from the studies were published, even seasoned **microbiologists** were stunned at the variety and numbers of marine microbes they had discovered.

Microbiologists had previously described around 6,000 different types of bacteria, but the evidence from these new studies showed that this number represented only the tiniest "drop in the ocean." Some data revealed more than 20,000 different kinds of microorganisms in just a single liter of seawater, most of them unidentified. Considering how the ocean's vast realm supports an impressive variety of **habitats,** specialists estimate that the ocean environment could easily harbor 10 million to 20 million different microscopic creatures, each of them having unique **characteristics** and **niches.** And even more intriguing was the discovery that up to 20% of the analyzed genetic material could not be matched to any known sort of microorganism. Because there is so much still to be learned about all earthly habitats, biologists have dubbed this sort of shadow life that functions behind the scenes without yet being identified as "biological dark matter."

Dr. David Thomassen, Chief Scientist, Department of Energy, aptly expressed the outcome of these studies: "Microbes rule the earth. Scientists estimate that there are more microbes on earth than there are stars in the universe—an estimated nonillion (one followed by 30 zeros). Microbes and their communities make up the foundation of the biosphere and sustain all life on earth."

- *In addition to bacteria, which other groups of microorganisms would likely be found in the plankton?*
- *What fields of microbiology would be involved in the further study of these planktonic microbes?*

To continue the Case Study, go to page 24.

*Dr. Venter was one of the main individuals behind the mapping of the human genome.

**To read more about this technique, called metagenomic analysis, look ahead to chapter 10.

1.1 The Scope of Microbiology

Expected Learning Outcomes

1. Define *microbiology* and *microorganisms,* and identify the major organisms included in the science of microbiology.
2. Name and define the primary areas included in microbiological studies.

As we observe the natural world, teeming with life, we cannot help but be struck by its beauty and complexity. But for every feature that is visible to the naked eye, there are millions of other features that are concealed beyond our sight because of their small size. This alternate microscopic universe is populated by a vast microbial menagerie that is equally beautiful and complex. To sum up the presence of microbes in one word, they are **ubiquitous.*** They are found in all natural habitats and most of those that have been created by humans. As scientists continue to explore remote and unusual environments, the one entity they always find is microbes. They exist deep beneath the polar ice caps, in the ocean to a depth of 7 miles, in hot springs and thermal vents, in toxic waste dumps, and even in the clouds.

Microbiology is a specialized area of biology that deals with tiny life forms that are not readily observed without magnification, which is to say they are **microscopic.*** These microscopic organisms are collectively referred to as **microorganisms, microbes,*** or several other terms, depending upon the purpose. Some people call them "germs" or "bugs" in reference to their role in infection and disease, but those terms have other biological meanings and perhaps place undue emphasis on the disagreeable reputation of microorganisms. The major groups of microorganisms included in this study are **bacteria, viruses, fungi, protozoa, algae,** and **helminths** (parasitic worms). As we will see in subsequent chapters, each group exhibits a distinct collection of biological characteristics. The nature of microorganisms makes them both easy and difficult to study. Easy, because they reproduce so rapidly and can usually be grown in large numbers in the laboratory. Difficult, because we can't observe or analyze them without special techniques, especially the use of microscopes (see chapter 3).

Microbiology is one of the largest and most complex of the biological sciences because it integrates subject matter from many diverse disciplines. Microbiologists study every aspect of microbes—their genetics, their physiology, characteristics that may be harmful or beneficial, the ways they interact with the environment, the ways they interact with other organisms, and their uses in industry and agriculture.

See **table 1.1** for an overview of some fields and occupations that involve basic study or applications in microbiology. Each major discipline in microbiology contains numerous subdivisions or specialties that deal with a specific subject area or field (table 1.1). In fact, many areas of this science have become so specialized that it is not uncommon for a microbiologist to spend an entire career concentrating on a single group or type of microbe, biochemical process, or disease.

Among the specialty professions of microbiology are:

- geomicrobiologists, who focus on the roles of microbes in the development of earth's crust (table 1.1B);
- marine microbiologists, who study the oceans and its smallest inhabitants;
- medical technologists, who do the tests that help diagnose pathogenic microbes and their diseases;
- nurse epidemiologists, who analyze the occurrence of infectious diseases in hospitals; and
- astrobiologists, who study the possibilities of organisms in space (see Case Study, page 29).

Studies in microbiology have led to greater understanding of many general biological principles. For example, the study of microorganisms established universal concepts concerning the chemistry of life (see chapters 2 and 8), systems of inheritance (see chapter 9), and the global cycles of nutrients, minerals, and gases (see chapter 26).

1.2 General Characteristics of Microorganisms and Their Roles in the Earth's Environments

Expected Learning Outcomes

3. Describe the basic characteristics of prokaryotic cells and eukaryotic cells and their evolutionary origins.
4. State several ways that microbes are involved in the earth's ecosystems.
5. Describe the cellular makeup of microorganisms and their size range, and indicate how viruses differ from cellular microbes.

The Origins and Dominance of Microorganisms

For billions of years, microbes have extensively shaped the development of the earth's habitats and influenced the evolution of other life forms. It is understandable that scientists searching for life on other planets first look for signs of microorganisms.

The fossil record uncovered in ancient rocks and sediments points to bacteria-like cells having existed on earth for at least 3.5 billion years **(figure 1.1).** Early microorganisms of this type dominated the earth's life forms for the first 2 billion years. These ancient cells were small, simple, and lacked specialized internal structures to carry out their functions. It is apparent that genetic material of these cells was not bound into a separate compartment called a nucleus or "karyon." The term assigned to cells and microbes of this type is **prokaryotic,*** meaning "before the nucleus." About 1.8 billion years ago, there appeared in the fossil record a more complex cell, which had developed a nucleus and various specialized internal structures called **organelles.*** These types of cells and organisms are defined as **eukaryotic*** in reference to their

* *ubiquitous* (yoo-bik′-wih-tis) L. *ubique,* everywhere and *ous,* having. Being, or seeming to be, everywhere at the same time.
* *microscopic* (my″-kroh-skaw′-pik) Gr. *mikros,* small, and *scopein,* to see.
* *microbe* (my′-krohb) Gr. *mikros,* small, and *bios,* life.

* *prokaryotic* (proh″-kar-ee-ah′-tik) Gr. *pro,* before, and *karyon,* nucleus. Sometimes spelled procaryotic and eucaryotic.
* *organelles* (or-gan′-elz) Gr. *organa,* tool, and *ella*, little.
* *eukaryotic* (yoo″-kar-ee-ah′-tik) Gr. *eu,* true or good, and *karyon,* nucleus.

TABLE 1.1 A Sampling of Fields and Occupations in Microbiology

A. Public Health Microbiology and Epidemiology

These branches monitor and control the spread of diseases in communities. Some of the institutions charged with this task are the U.S. Public Health Service (USPHS) and the Centers for Disease Control and Prevention (CDC). The CDC collects information and statistics on diseases from around the United States and publishes it in a newsletter, *The Morbidity and Mortality Weekly Report* (see chapter 13).

A parasite specialist examines leaf litter for the presence of black-legged ticks—the carriers of Lyme disease.

B. Environmental Microbiology

This field encompasses the study of microorganisms and their ecological relationships in such natural habitats as soil and water.

A geomicrobiologist from NASA collects samples from Mono Lake as part of an environmental study determining survival strategies of extreme bacteria.

C. Biotechnology

This branch is defined by any process that harnesses the actions of living things to derive a desired product, ranging from beer to stem cells. It includes industrial microbiology, which uses microbes to produce and harvest large quantities of such substances as vaccines, vitamins, drugs, and enzymes (see chapters 10 and 27).

A technician tests the effectiveness of microorganisms in the production of new sources of energy.

D. Immunology

This branch studies the complex web of protective substances and reactions caused by invading microbes and other harmful entities. It includes such diverse areas as blood testing, vaccination, and allergy (see chapters 15, 16, and 17).

A CDC virologist examines cultures of influenza virus that are used in producing vaccines. This work requires high-level biohazard containment.

TABLE 1.1 *(continued)*

E. Genetic Engineering and Recombinant DNA Technology

These interrelated fields involve deliberate alterations of the genetic makeup of organisms to create novel microbes, plants, and animals with unique behavior and physiology. This is a rapidly expanding field that often complements biotechnology (see chapter 10).

A bacteriologist from the U.S. Department of Energy checks cultures of genetically modified bacteria for growth.

F. Agricultural Microbiology

This branch is concerned with the relationships between microbes and domesticated plants and animals. Plant specialists focus on plant diseases, soil fertility, and nutritional interactions. Animal specialists work with infectious diseases and other interactions between animals and microorganisms.

Microbiologists from the U.S. Food and Drug Administration collect soil samples to detect animal pathogens.

G. Food Microbiologists

These scientists are concerned with the impact of microbes on the food supply, including such areas as food spoilage, food-borne diseases, and production.

A U.S. Department of Agriculture technician observes tests for the presence of *Escherichia coli* in foods.

H. Branches of Microbiology

Branch	Chapter	Involved in the Study of:
Bacteriology	4	The bacteria—small single-celled prokaryotic organisms
Mycology	5, 22	The fungi, a group of eukaryotes that includes both microscopic eukaryotes (molds and yeasts) and larger organisms (mushrooms, puffballs)
Protozoology	5, 23	The protozoa—animal-like and mostly single-celled eukaryotes
Virology	6, 24, 25	Viruses—minute, noncellular particles that parasitize cells
Parasitology	5, 23	Parasitism and parasitic organisms—traditionally including pathogenic protozoa, helminth worms, and certain insects
Phycology or Algology	5	Simple photosynthetic eukaryotes, the algae, ranging from single-celled forms to large seaweeds
Morphology	4, 5, 6	The detailed structure of microorganisms
Physiology	7, 8	Microbial function (metabolism) at the cellular and molecular levels
Taxonomy	1, 4, 5, 17	Classification, naming, and identification of microorganisms
Microbial Genetics, Molecular Biology	9, 10	The function of genetic material and biochemical reactions that make up a cell's metabolism
Microbial Ecology	7, 26	Interrelationships between microbes and the environment; the roles of microorganisms in the nutrient cycles and natural ecosystems

A medical microbiologist tests specimens for evidence of antibodies to the human immunodeficiency virus (HIV).

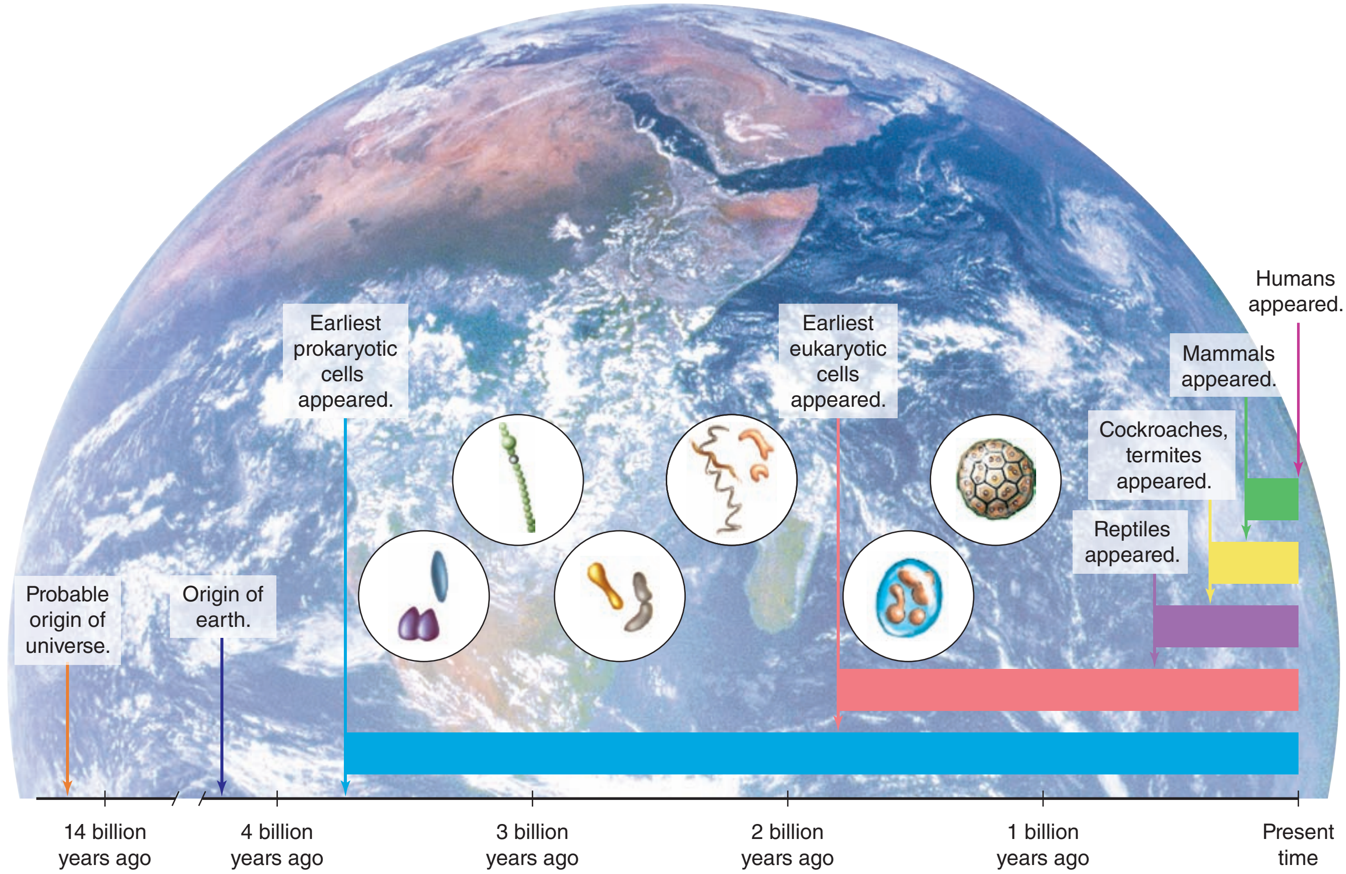


Figure 1.1 Evolutionary time line. The first simple prokaryotes appeared approximately 3.5 billion years ago, and the first eukaryotes arose about 2 billion years ago. Although these appearances seem abrupt, hundreds of millions of years of earth's history passed while they were evolving to these stages. The fossil record for these periods are incomplete because most of the tiny microbes were too delicate to fossilize.

"true" nucleus. **Figure 1.2** compares the two cell types and includes some examples of viruses, for comparison. In chapter 5, we will learn more about the origins of eukaryotic cells—they didn't arise suddenly out of nowhere—they evolved over millennia from prokaryotic cells through an intriguing process called endosymbiosis. The early eukaryotes, probably similar to algae and protozoa, started lines of evolution that eventually gave rise to fungi, plants, and multicellular animals such as worms and insects. You can see from figure 1.1 how long that took! The bacteria preceded even the earliest animals by about 3 billion years. This is a good indication that humans are not likely to, nor should we try to, eliminate microorganisms from our environment. They are the ultimate survivors.

The Cellular Organization of Microorganisms

As a general rule, prokaryotic cells are smaller than eukaryotic cells, and in addition to lacking a nucleus, as previously mentioned, they lack organelles, which are structures in cells bound by one or more membranes. Examples of organelles include the mitochondria and Golgi complexes, and several others, which perform specific

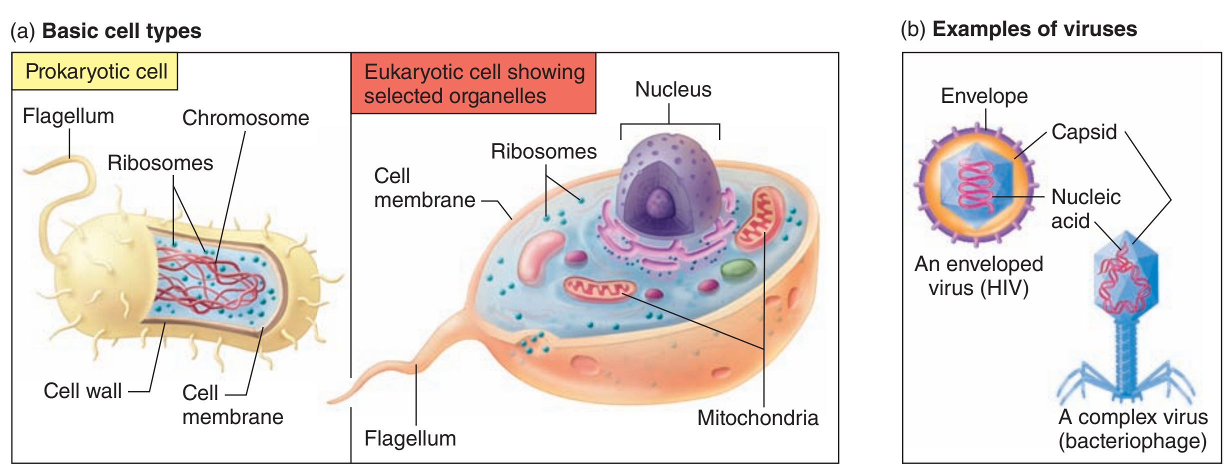
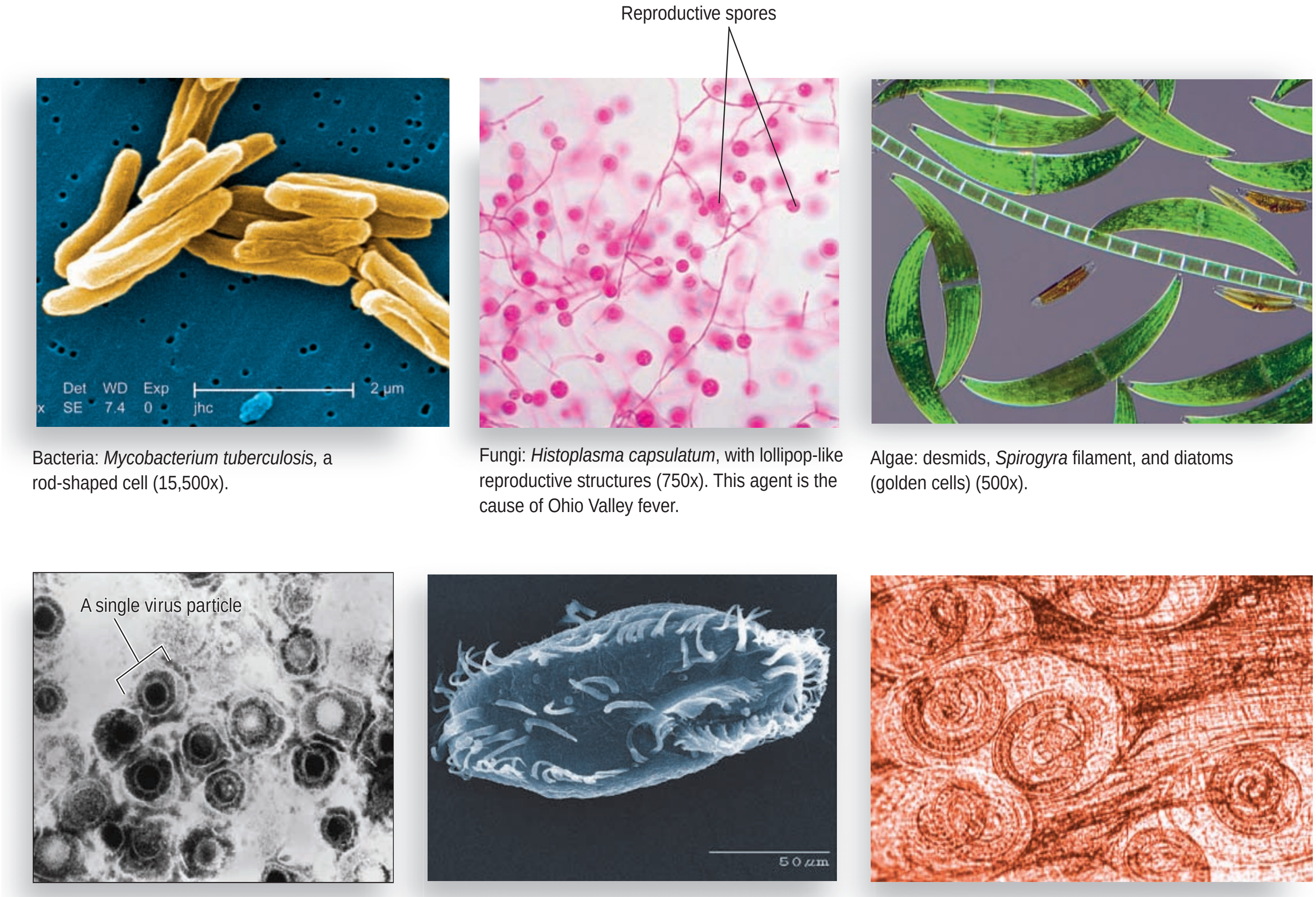


Figure 1.2 Basic structure of cells and viruses. (a) Comparison of a prokaryotic cell and a eukaryotic cell. **(b)** Two examples of viruses. These cell types and viruses are discussed in more detail in chapters 4, 5, and 6.



Bacteria: *Mycobacterium tuberculosis,* a rod-shaped cell (15,500x).

Fungi: *Histoplasma capsulatum*, with lollipop-like reproductive structures (750x). This agent is the cause of Ohio Valley fever.

Algae: desmids, *Spirogyra* filament, and diatoms (golden cells) (500x).

Virus: *Herpes simplex,* the cause of cold sores (100,000x).

Protozoa: A protozoan, *Oxytricha trifallax* bearing tufts of cilia that function like tiny legs (3,500x).

Helminths: Roundworms of *Trichinella spiralis* coiled in the muscle of a host (250x). This worm causes trichinellosis.

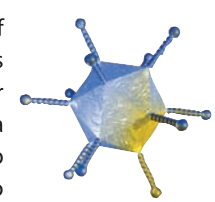
Figure 1.3 The six basic types of microorganisms. Organisms are not shown at the same magnifications; approximate magnification is provided. To see these microorganisms arrayed more accurately to scale, look for them in figure 1.4.

functions such as transport, feeding, energy release and use, and synthesis. Prokaryotes perform similar functions, but they lack dedicated organelles to carry them out (figure 1.2).

The body plan of most microorganisms consists of a single cell or clusters of cells **(figure 1.3).** All prokaryotes are microorganisms and include the bacteria and archaea (see figure 1.14). Only some of the eukaryotes are microorganisms: primarily algae, protozoa, molds and yeasts (types of fungi), and certain animals such as worms and arthropods. These last two groups are not all microscopic, but certain members are still included in the study because worms can be involved in infections and may require a microscope to identify them. Some arthropods such as fleas and ticks may also be carriers of infectious diseases. Additional coverage on cell types and microorganisms appears in chapters 4 and 5.

Where Do the Viruses Fit?

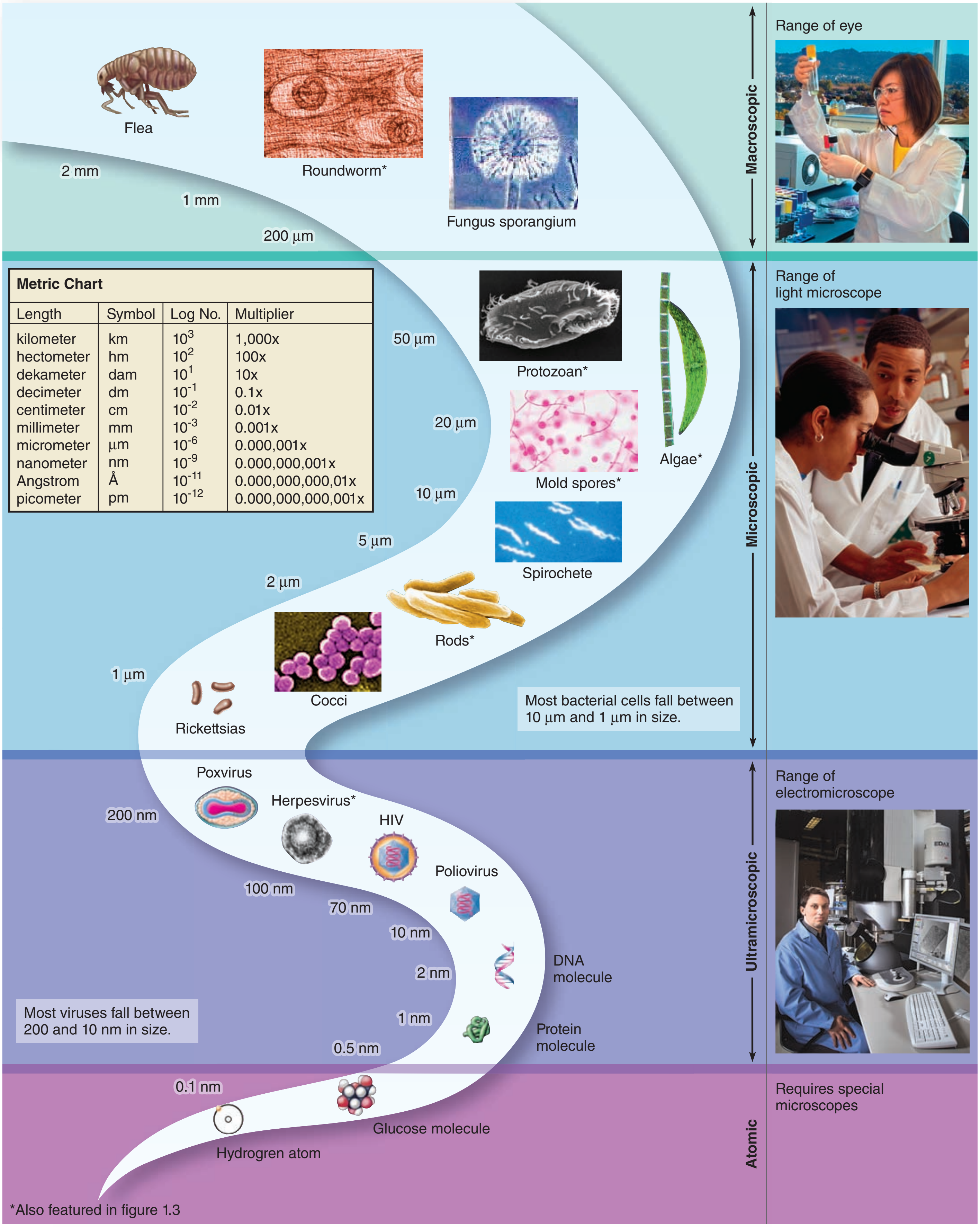
Viruses are considered one type of microbe because they are microscopic and can cause infections and disease, but they are not cells. They are small particles that exist at a level of complexity somewhere between large molecules and cells (see figure 1.4). Viruses are much simpler than cells; they are composed essentially of a small amount of hereditary material wrapped up in a protein covering. Some biologists refer to viruses as parasitic particles; others consider them to be very primitive organisms. Despite this slight disagreement, the impact of viruses is undeniable. Not only are they the most common microbes on earth, but they invade their hosts' cells and inflict serious damage and death.



An adenovirus

Microbial Dimensions: How Small Is Small?

When we say that microbes are too small to be seen with the unaided eye, what sorts of dimensions are we talking about? This concept is best visualized by comparing microbial groups with some organisms of the macroscopic world and also with the molecules and atoms of the molecular world **(figure 1.4).** The dimensions



Metric Chart

Length	Symbol	Log No.	Multiplier
kilometer	km	10^{3}	1,000x
hectometer	hm	10^{2}	100x
dekameter	dam	10^{1}	10x
decimeter	dm	10^{-1}	0.1x
centimeter	cm	10^{-2}	0.01x
millimeter	mm	10^{-3}	0.001x
micrometer	µm	10^{-6}	0.000,001x
nanometer	nm	10^{-9}	0.000,000,001x
Angstrom	Å	10^{-11}	0.000,000,000,01x
picometer	pm	10^{-12}	0.000,000,000,001x

Figure 1.4 The sizes of the smallest organisms and objects. Even though they are all very small, they still display extensive variation in size. This illustration organizes the common measurements used in microbiology along with examples of organisms or items that fall into these measurement ranges. The scale includes macroscopic, microscopic, ultramicroscopic, and atomic dimensions. Most microbes we study measure somewhere between 100 micrometers (µm) and 10 nanometers (nm) overall. The examples are more or less to scale within a size zone but not between size zones.

of macroscopic organisms are usually given in centimeters (cm) and meters (m), whereas those of most microorganisms fall within the range of micrometers (μm) and, sometimes, nanometers (nm) and millimeters (mm). The size range of most microbes extends from the smallest viruses, measuring around 10 nm and actually not much bigger than a large molecule, to protozoans measuring 3 to 4 mm and visible with the naked eye.

Microbial Involvement in Energy and Nutrient Flow

The microbes in all natural environments have lived and evolved there for billions of years. We do not yet know everything they do, but it is likely they are vital components of the structure and function of these ecosystems and critical to the operations of the earth.

Microbes are deeply involved in the flow of energy and food through the earth's ecosystems.[1] Most people are aware that plants carry out **photosynthesis,** which is the light-fueled conversion of carbon dioxide to organic material, accompanied by the formation of oxygen. But microorganisms were photosynthesizing long before the first plants appeared. In fact, they were responsible for changing the atmosphere of the earth from one without oxygen to one with oxygen. Today photosynthetic microorganisms (including algae) account for more than 50% of the earth's photosynthesis, contributing the majority of the oxygen to the atmosphere **(figure 1.5*a*).**

Another process that helps keep the earth in balance is the process of biological **decomposition** and nutrient recycling. Decomposition involves the breakdown of dead matter and wastes into simple compounds that can be directed back into the natural cycles of living things **(figure 1.5*b*).** If it were not for multitudes of bacteria and fungi, many chemical elements would become locked up and unavailable to organisms. In the long-term scheme of things, microorganisms are the main forces that drive the structure and content of the soil, water, and atmosphere. For example:

- Earth's temperature is regulated by "greenhouse gases," such as carbon dioxide and methane, that create an insulation layer in the atmosphere and help retain heat. A significant proportion of these gases is produced by microbes living in the environment and the digestive tracts of animals.
- Recent estimates propose that, based on weight and numbers, up to 50% of all organisms exist within and beneath the earth's crust in soil, rocks, and even the frozen Antarctic **(figure 1.5*c*).** It is increasingly evident that this enormous underground community of microbes is a major force in weathering, mineral extraction, and soil formation.
- Bacteria and fungi live in complex associations with plants. They assist the plants in obtaining nutrients and water and may protect them against disease. Microbes form similar interrelationships with animals, notably as residents of numerous bodily sites.

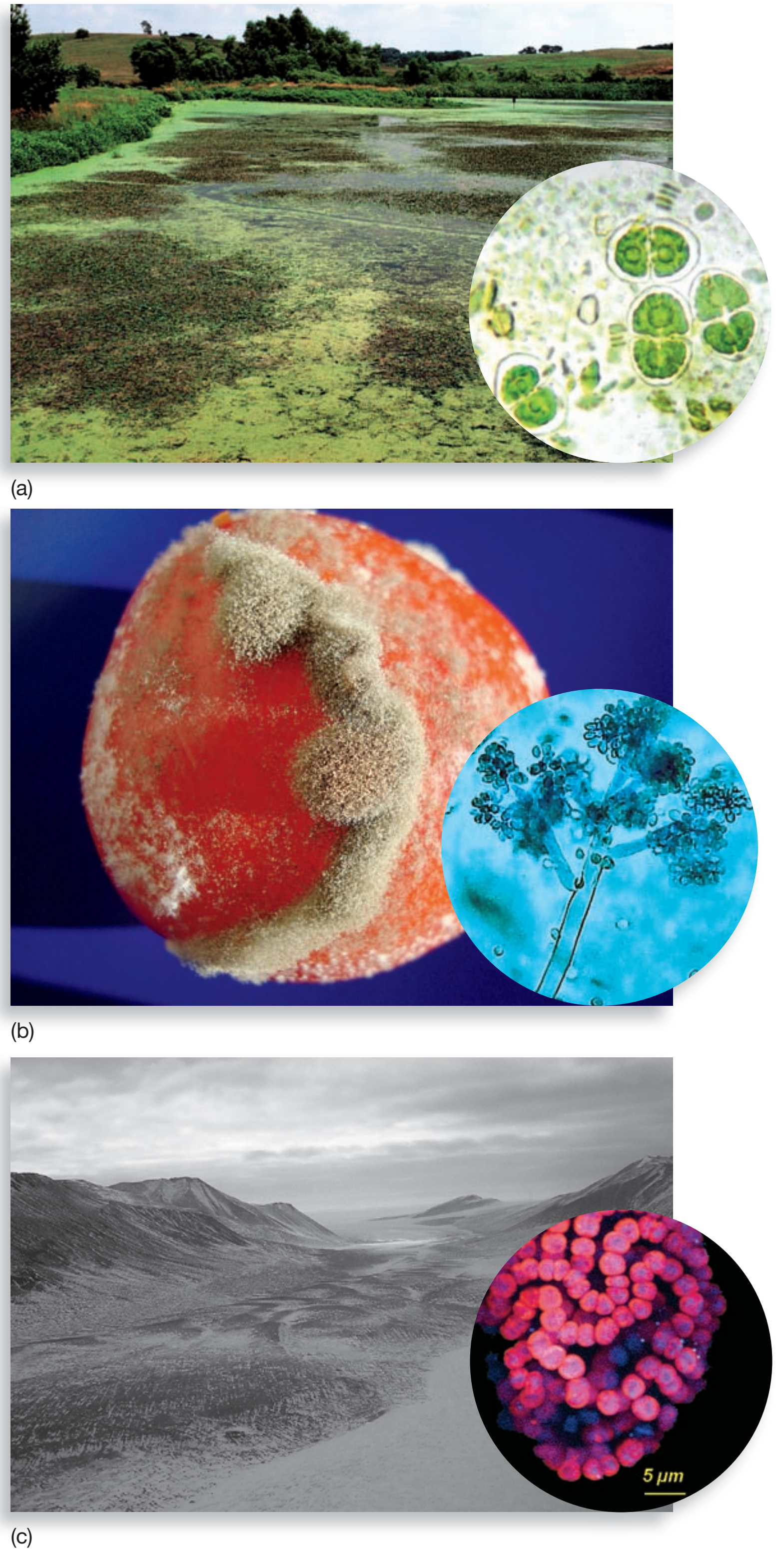


Figure 1.5 A microscopic wonderland. (a) A summer pond is heavily laden with surface scum that reveals several different types of green algae called desmids (600×). **(b)** A rotting tomato being invaded by a fuzzy forest of mold. The fungus is *Botrytis*, a common decomposer of tomatoes and grapes (250×). **(c)** Even a dry lake in Antarctica, one of the coldest places on earth (−35°C), can harbor microbes under its icy sheet. Here we see a red cyanobacterium, *Nostoc* (3,000×), that has probably been frozen in suspended animation there for 3,000 years. This is one kind of habitat on earth that may well be a model for conditions on Mars.

1. Ecosystems are communities of living organisms and their surrounding environment.

Check Your Progress SECTIONS 1.1–1.2

1. Define what is meant by the term "microorganism" and outline the important contributions microorganisms make to the earth's ecosystems.
2. Describe five different ways in which humans exploit microorganisms for our benefit.
3. Identify the groups of microorganisms included in the scope of microbiology, and explain the criteria for including these groups in the field.
4. Observe figure 1.3 and place the microbes pictured in a size ranking, going from smallest to largest. Use the magnification as your gauge.
5. Construct a table that displays all microbial groups based on what kind of cells they have or do not have.
6. Explain this statement: Microorganisms—we need to live with them because we can't live without them.

1.3 Human Use of Microorganisms

Expected Learning Outcome

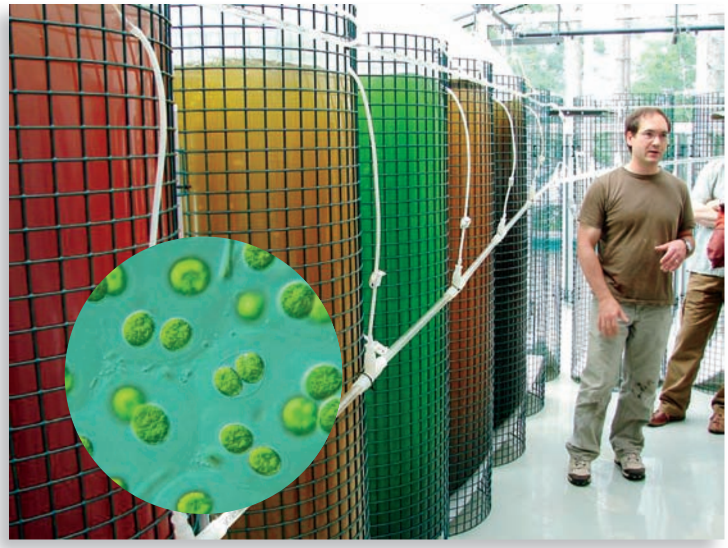
6. Discuss the ways microorganisms can be used to create solutions for environmental problems and industrial products.

The incredible diversity and versatility seen in microbes make them excellent candidates for solving human problems. By accident or choice, humans have been using microorganisms for thousands of years to improve life and even to further human progress. Yeasts, a type of microscopic fungi, cause bread to rise and ferment sugar to make alcoholic beverages. Historical records show that households in ancient Egypt kept moldy loaves of bread to apply directly to wounds and lesions, which was probably the first use of penicillin! The manipulation of microorganisms to make products in an industrial setting is called **biotechnology.*** One newer application of this process uses farmed algae to extract a form of oil (biodiesel) to be used in place of petroleum products **(figure 1.6*a*).**

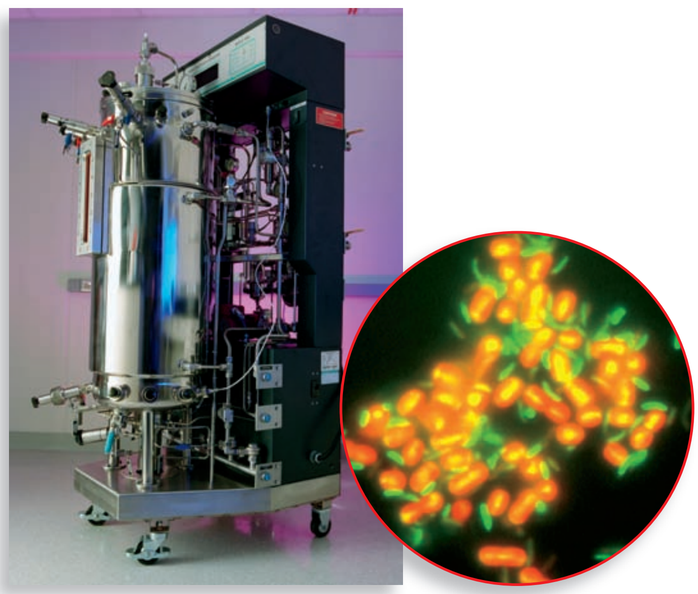
Genetic engineering is a newer area of biotechnology that manipulates the genetics of microbes, plants, and animals for the purpose of creating new products and genetically modified organisms. One powerful technique for designing new organisms is termed **recombinant DNA.** This technology makes it possible to deliberately alter DNA[2] and to switch genetic material from one organism to another. Bacteria and fungi were some of the first organisms to be genetically engineered, because their relatively simple genetic material is readily manipulated in the laboratory. Recombinant DNA technology has unlimited potential in terms of medical, industrial, and agricultural uses. Microbes can be engineered to synthesize desirable proteins such as drugs, hormones, and enzymes (see table 1.1*C*).

Among the genetically unique organisms that have been designed by bioengineers are bacteria that contain a natural pesticide, yeasts that produce human hormones, pigs that produce hemoglobin, and plants that are resistant to disease (see table 1.1*E*). The techniques have also paved the way for characterizing human genetic material and diseases.

Another way of tapping into the unlimited potential of microorganisms is the relatively new science of **bioremediation.*** This



(a)



(b)

Figure 1.6 Microbes at work. (a) A scientist from the National Oceanic and Atmospheric Agency (NOAA) demonstrates a series of biodiesel reactors that culture single-celled algae (inset 750×) as a source of oil. This new "green" renewable energy source looks very promising. **(b)** Biotechnology meets bioremediation. Scientists at Pacific Northwest National Laboratories (PNNL) test the capacity of two newly discovered bacteria—*Shewanella* (green) and *Synechococcus* (yellow) (1,000×)—to reduce and detoxify radioactive waste. The process, carried out in large bioreactors, could speed the clean up of hazardous nuclear waste deposits.

* *biotechnology* (by′-oh-tek-nol″-oh-gee) The use of microbes or their products in the commercial or industrial realm.

2. DNA, or deoxyribonucleic acid, the chemical substance that comprises the genetic material of organisms.

* *bioremediation* (by′-oh-ree-mee-dee-ay″-shun) *bios,* life; *re*, again; *mederi,* to heal. The use of biological agents to remedy environmental problems.