FOUNDATIONS IN MICROBIOLOGY

10th EDITION

KATHLEEN PARK
TALARO

BARRY
CHESS

Mc Graw Hill Education

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Photo of Kathy Park Talaro (p. vi): Courtesy of Dave Bedrosian; Photo of Barry Chess (p. vi): Courtesy of Josh Chess

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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 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 by 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.

Barry Chess has been teaching microbiology at Pasadena City College for 20 years. He received his Bachelor's and Master's degrees from the California State University and did postgraduate work at the University of California, 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 increase student success. He has written cases for the National Center for Case Study Teaching in Science and given talks at national meetings on the effectiveness of case studies in the classroom. His laboratory manual, *Laboratory Applications in Microbiology: A Case Study Approach,* is currently in its third edition. He feels very fortunate to be collaborating with Kathy Talaro, with whom he has worked in the classroom for more than a decade, on this tenth edition. Barry is a member of the American Society for Microbiology and the American Association for the Advancement of Science 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.

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 our other aim is 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.

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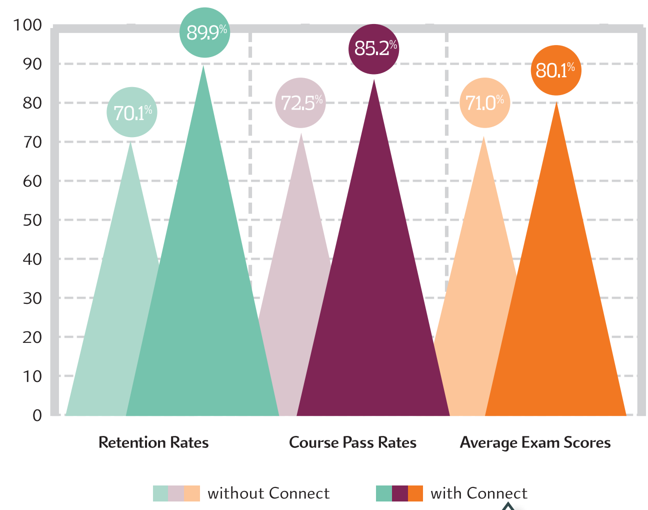

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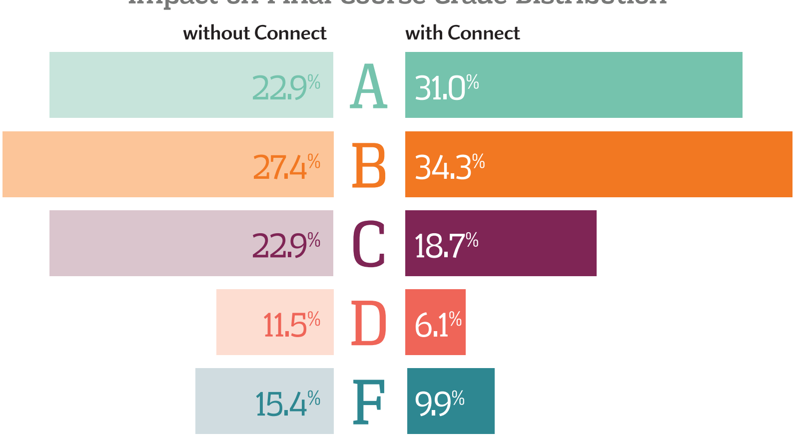

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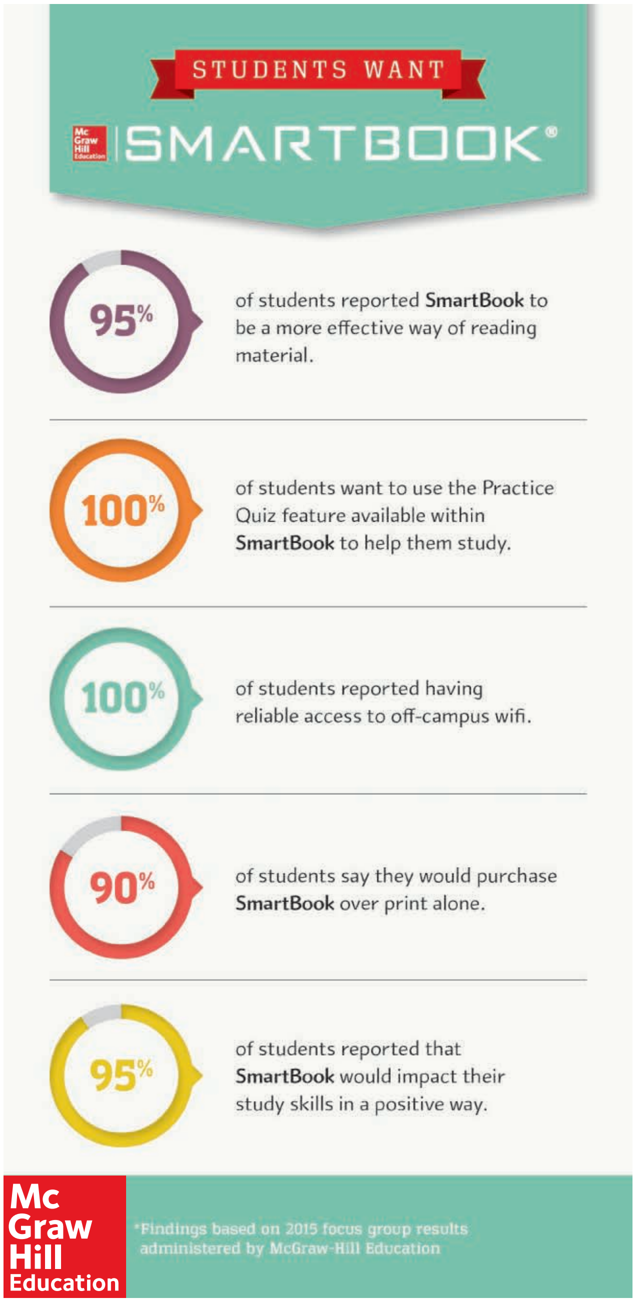

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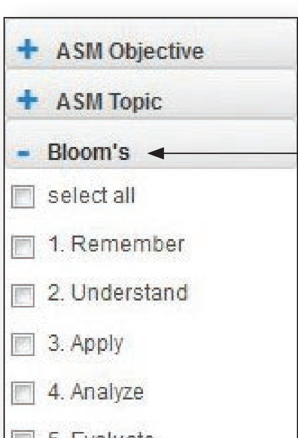

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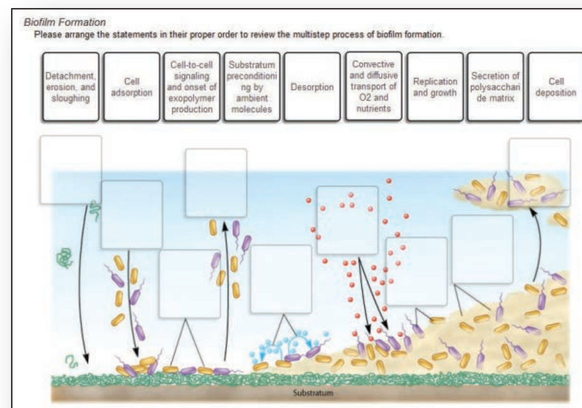

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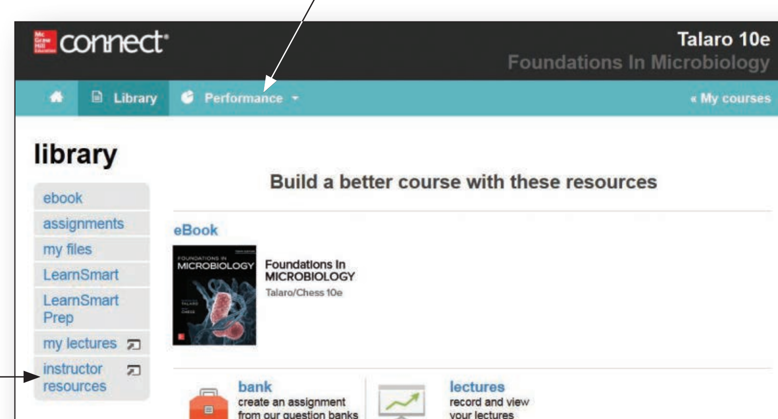

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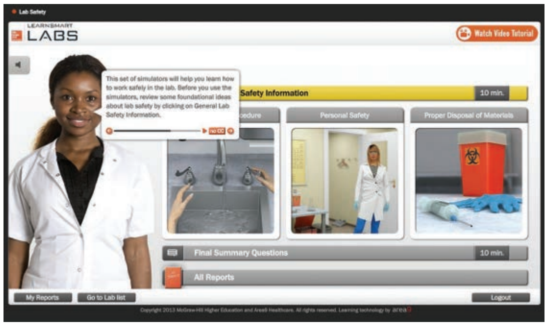


LearnSmart Labs® is an adaptive simulated lab experience that brings meaningful scientific exploration to students. Through a series of adaptive questions, LearnSmart Labs identifies a student's knowledge gaps and provides resources to quickly and efficiently close those gaps. Once students have mastered the necessary basic skills and concepts, they engage in a highly realistic simulated lab experience that allows for mistakes and the execution of the scientific method.

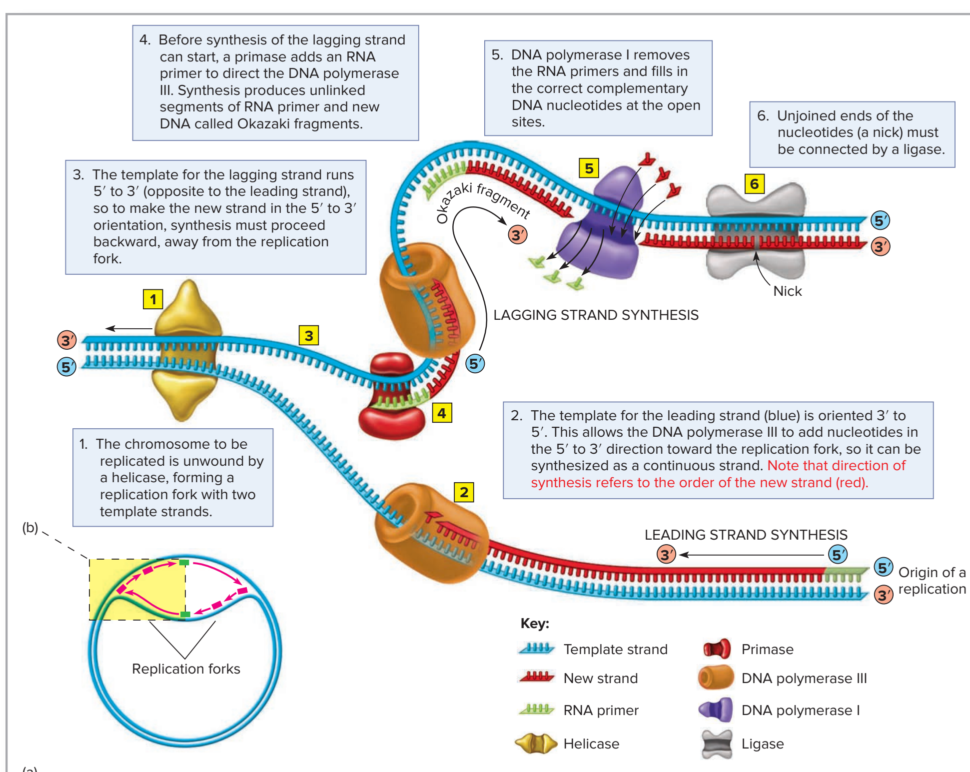
LearnSmart® Prep is an adaptive learning tool that prepares students for college-level work in Microbiology. LearnSmart Prep individually identifies concepts the student does not fully understand and provides learning resources to teach essential concepts so he or she enters the classroom prepared. Data-driven reports highlight areas where students are struggling, helping to accurately identify weak areas.

The **Profile** of a Student Success 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 tenth 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 tenth edition continues to meet these goals with the most digitally integrated, up-to-date, and pedagogically important revision yet.

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, that 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.

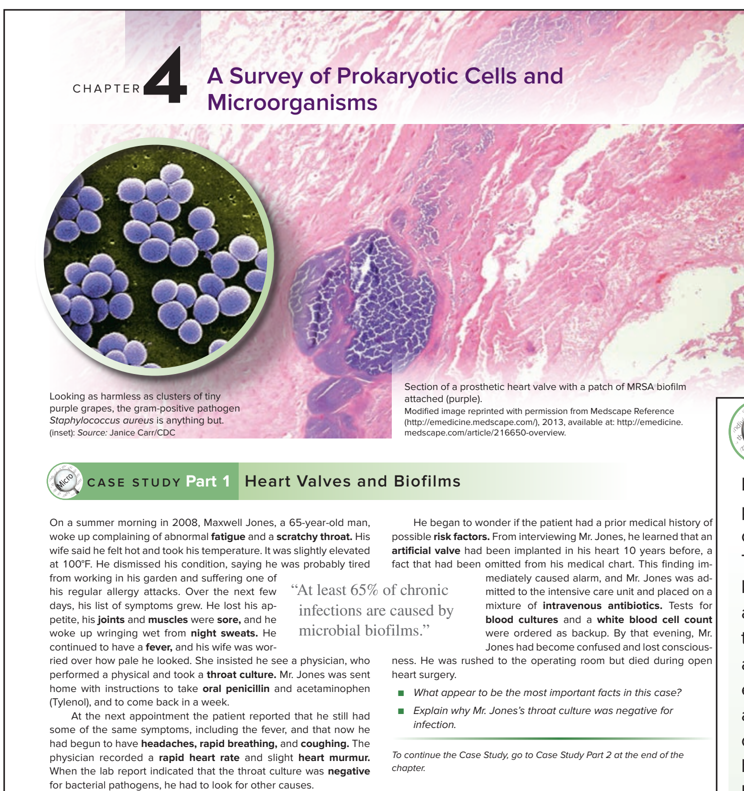


Kathy Talaro introduces new art to a revision by carefully sketching out what she envisions in precise detail, with accompanying instructions to the illustrator. The result is accurate, beautifully rendered art that helps difficult concepts come to life.

The **Structure** of a Student Success 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 Parts 1 and 2 of the Case Study 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 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.
(inset): *Source:* Janice Carr/CDC

Section of a prosthetic heart valve with a patch of MRSA biofilm attached (purple).
Modified image reprinted with permission from Medscape Reference (http://emedicine.medscape.com/), 2013, available at: http://emedicine.medscape.com/article/216650-overview.

CASE STUDY Part 1 Heart Valves and Biofilms

On a summer morning in 2008, 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 list of symptoms 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.

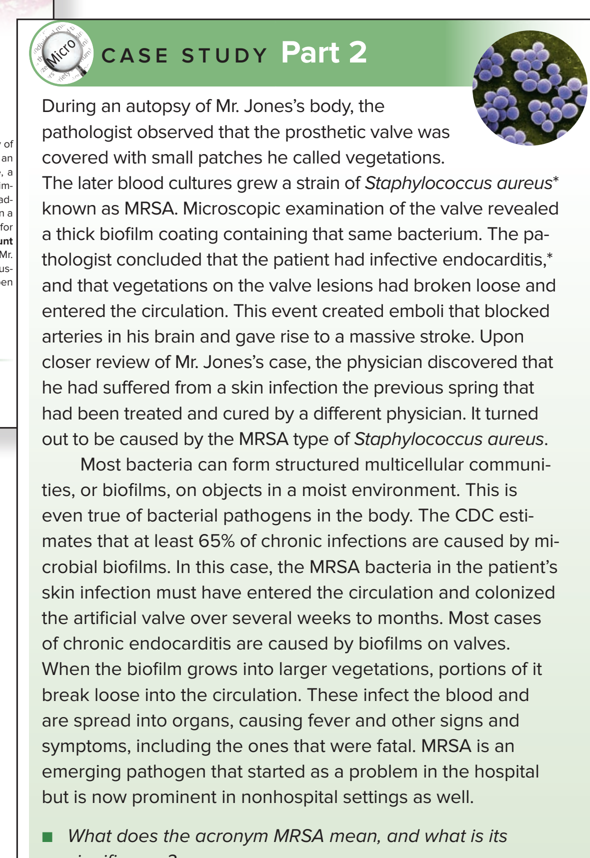
At the next appointment the patient reported that he still had some of the same symptoms, including the fever, and that now he had begun to have **headaches, rapid breathing,** and **coughing.** The physician recorded a **rapid heart rate** and slight **heart murmur.** When the lab report indicated that the throat culture was **negative** for bacterial pathogens, he had to look for other causes.

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

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.

- *What appear to be the most important facts in this case?*
- *Explain why Mr. Jones's throat culture was negative for infection.*

To continue the Case Study, go to Case Study Part 2 at the end of the chapter.



CASE STUDY **Part 2**

During an autopsy of Mr. Jones's body, the pathologist observed that the prosthetic valve was covered with small patches he called vegetations. The later blood cultures grew a strain of *Staphylococcus aureus** known as MRSA. Microscopic examination of the valve revealed a thick biofilm coating containing that same bacterium. The pathologist concluded that the patient had infective endocarditis,* and that vegetations on the valve lesions had broken loose and entered the circulation. This event created emboli that blocked arteries in his brain and gave rise to a massive stroke. Upon closer review of Mr. Jones's case, the physician discovered that he had suffered from a skin infection the previous spring that had been treated and cured by a different physician. It turned out to be caused by the MRSA type of *Staphylococcus aureus*.

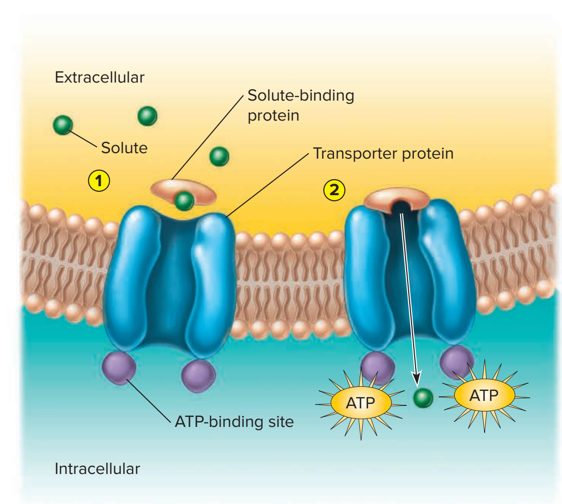
Most bacteria can form structured multicellular communities, or biofilms, on objects in a moist environment. This is even true of bacterial pathogens in the body. The CDC estimates that at least 65% of chronic infections are caused by microbial biofilms. In this case, the MRSA bacteria in the patient's skin infection must have entered the circulation and colonized the artificial valve over several weeks to months. Most cases of chronic endocarditis are caused by biofilms on valves. When the biofilm grows into larger vegetations, portions of it break loose into the circulation. These infect the blood and are spread into organs, causing fever and other signs and symptoms, including the ones that were fatal. MRSA is an emerging pathogen that started as a problem in the hospital but is now prominent in nonhospital settings as well.

- *What does the acronym MRSA mean, and what is its significance?*

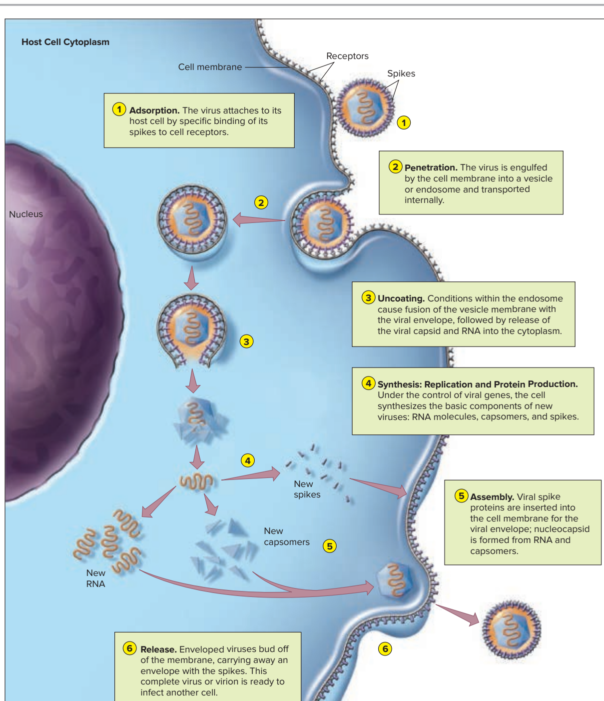
The **Art** of a Student Success Learning Tool

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.



Process Figures

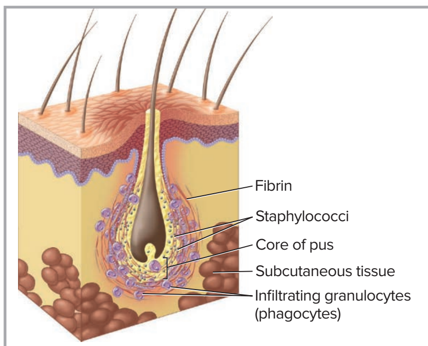
Many difficult microbiological concepts are best portrayed by breaking them down into stages that students will find easy to follow. These process figures show each step clearly numbered within a yellow circle and correlated to accompanying narrative to benefit all types of learners. A distinctive process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

The **Relevance** of a Student Success Learning Tool

Real clinical photos help students visualize

resolved with no complications, they can lead to infections of subcutaneous tissues. A **furuncle*** (boil) results when the inflammation of a single hair follicle or sebaceous gland progresses into a

* *furuncle* (fur′-unkl) L. *furunculus,* little thief.



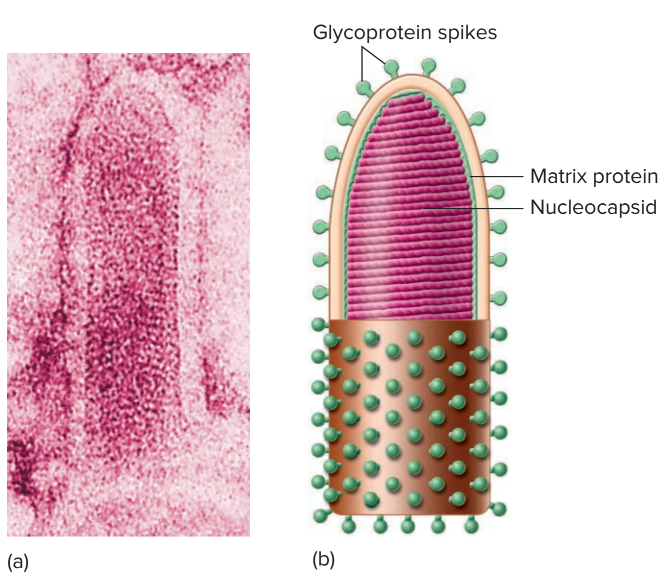
(a) Sectional view of a boil or furuncle, a single pustule that develops in a hair follicle or gland and is the classic lesion of the species. The inflamed infection site becomes abscessed when masses of phagocytes, bacteria, and fluid are walled off by fibrin.

(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).

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.



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.

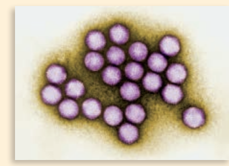
The **Purpose** of a Student Success Learning Tool

Secret World of Microbes

The living world abounds with incredible, fascinating microbes that have yet to be discovered or completely understood. This feature enriches 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.

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, which 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!



Does this virus make us look fat?
Source: CDC

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.

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 adipocytes (fat cells). This increase in both the number and the size of fat cells adds adipose tissue, more fat production and storage, and more body fat. Simultaneously, the adipocytes may also store more sugar, helping to keep blood sugar levels under control and maintaining insulin sensitivity to glucose. In general, such an association does not prove causation, but it certainly warrants additional research.

Using information you have learned about viruses, explain how viruses could become a permanent component of an organism's genetic material. *Answer available on Connect.*

Check Your Progress SECTION 13.1

1. Describe the significant relationships that humans have with microbes.
2. Explain what is meant by *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 betwee
7. Explain the factors newborn intestine ar

6.1 Overview of Viruses

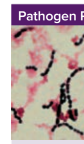
Expected Learning Outcomes

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 numbered section in the book 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 Connect.

Pathogen Profile #2 *Streptococcus pyogenes*



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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 Profiles

Pathogen Profiles are abbreviated snapshots of the major pathogens in each disease chapter. The pathogen is featured in a micrograph, along with a description of the microscopic morphology, identification descriptions, habitat information, and virulence factors. Artwork displays the primary infections/disease, as well as the organs and systems primarily impacted.

Pathogen Profile #3 *Clostridium difficile*

Source: CDC

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

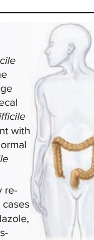
Identified by Gram reaction and endospore formation. *Clostridium* is differentiated from *Bacillus* as the former is typically a strict anaerobe and the latter is not. ELISA is often used to detect toxins of *C. difficile* in fecal samples.

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* infection (CDI) 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 a Student Success Learning Tool

Pedagogy created to promote active learning

CLINICAL CONNECTIONS

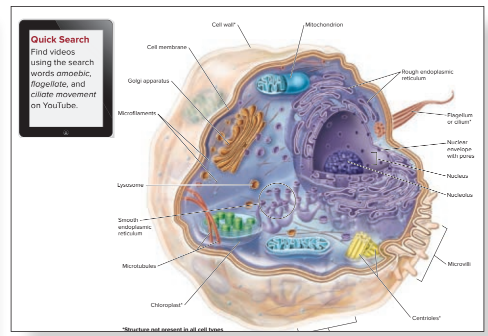
An Outbreak of Fungal Meningitis

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 vials of medication to medical facilities for injections to control pain. These vials were sent to 23 states and used to inject the drug into the spinal columns 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 the 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 controls, along with dirty preparation rooms. Mold spores were introduced during filling of the vials, and because the medication lacked preservatives, they survived and grew. The owner of the compounding pharmacy and the head pharmacist were each charged with 25 counts of second-degree murder, their trial is expected to start in late 2016.

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 on Connect.***



Quick Search

This 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 helps students 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.

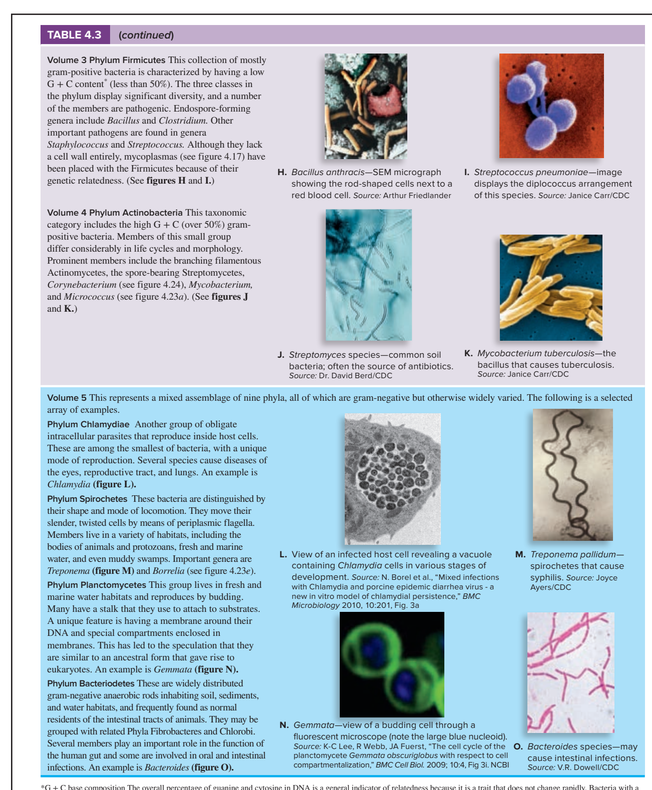


TABLE 4.3 *(continued)*

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. *Source:* Arthur Friedlander

I. *Streptococcus pneumoniae*—image displays the diplococcus arrangement of this species. *Source:* Janice Carr/CDC

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. *Source:* Dr. David Berd/CDC

K. *Mycobacterium tuberculosis*—the bacillus that causes tuberculosis. *Source:* Janice Carr/CDC

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. *Source:* N. Borel et al., "Mixed infections with Chlamydia and porcine epidemic diarrhea virus - a new in vitro model of chlamydial persistence," *BMC Microbiology* 2010, 10:201, Fig. 3a

M. *Treponema pallidum*—spirochetes that cause syphilis. *Source:* Joyce Ayers/CDC

N. *Gemmata*—view of a budding cell through a fluorescent microscope (note the large blue nucleoid). *Source:* K-C Lee, R Webb, JA Fuerst, "The cell cycle of the planctomycete *Gemmata obscuriglobus* with respect to cell compartmentalization," *BMC Cell Biol.* 2009; 10:4, Fig 3i. NCBI

O. *Bacteroides* species—may cause intestinal infections. *Source:* V.R. Dowell/CDC

*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.

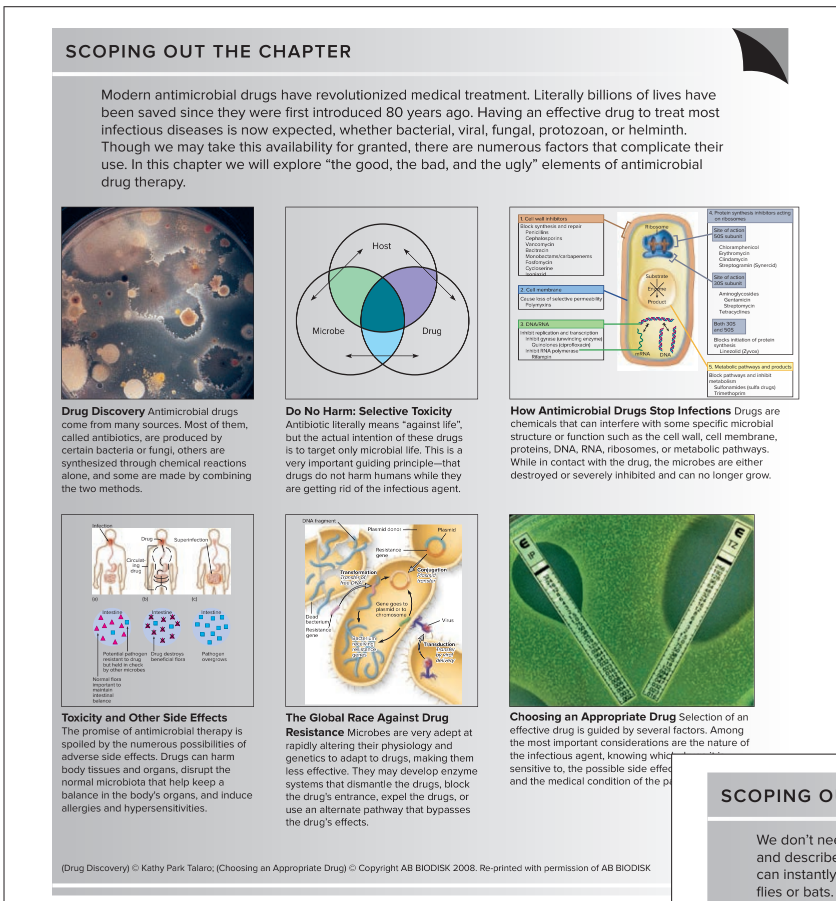
5. A mnemonic device to keep track of this is *LEO* says *GER: L*ose *E*lectrons *O*xidized; *G*ain *E*lectrons *R*educed.

Footnotes

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

Scoping Out The Chapter

This new feature follows the opening case study in Chapters 1-17 and 26-27. Students are provided with a descriptive pictorial guide for the main topics covered within these respective chapters.



SCOPING OUT THE CHAPTER

Modern antimicrobial drugs have revolutionized medical treatment. Literally billions of lives have been saved since they were first introduced 80 years ago. Having an effective drug to treat most infectious diseases is now expected, whether bacterial, viral, fungal, protozoan, or helminth. Though we may take this availability for granted, there are numerous factors that complicate their use. In this chapter we will explore "the good, the bad, and the ugly" elements of antimicrobial drug therapy.

Drug Discovery Antimicrobial drugs come from many sources. Most of them, called antibiotics, are produced by certain bacteria or fungi, others are synthesized through chemical reactions alone, and some are made by combining the two methods.

Do No Harm: Selective Toxicity Antibiotic literally means "against life", but the actual intention of these drugs is to target only microbial life. This is a very important guiding principle—that drugs do not harm humans while they are getting rid of the infectious agent.

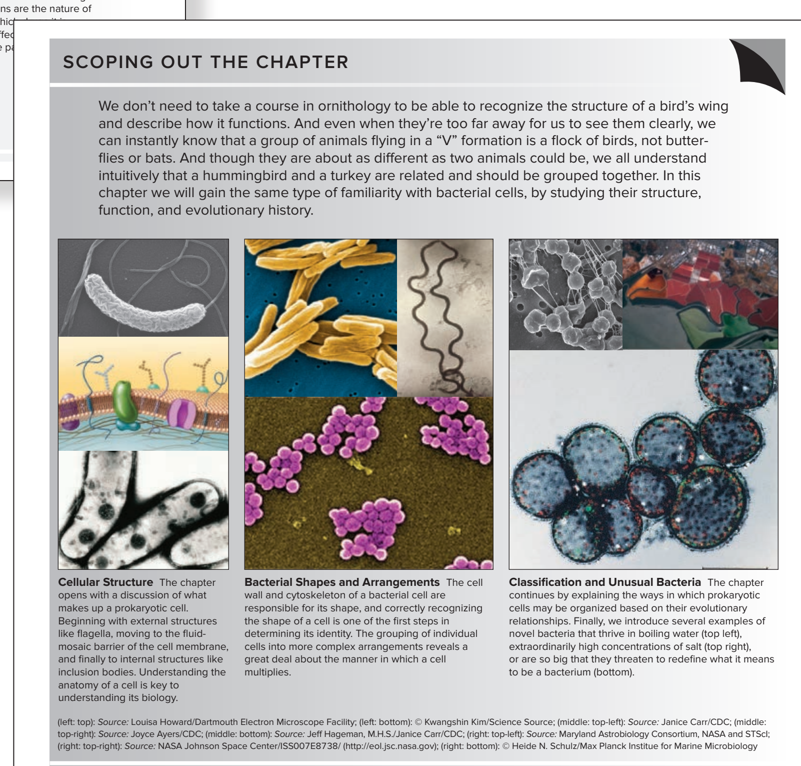
How Antimicrobial Drugs Stop Infections Drugs are chemicals that can interfere with some specific microbial structure or function such as the cell wall, cell membrane, proteins, DNA, RNA, ribosomes, or metabolic pathways. While in contact with the drug, the microbes are either destroyed or severely inhibited and can no longer grow.

Toxicity and Other Side Effects The promise of antimicrobial therapy is spoiled by the numerous possibilities of adverse side effects. Drugs can harm body tissues and organs, disrupt the normal microbiota that help keep a balance in the body's organs, and induce allergies and hypersensitivities.

The Global Race Against Drug Resistance Microbes are very adept at rapidly altering their physiology and genetics to adapt to drugs, making them less effective. They may develop enzyme systems that dismantle the drugs, block the drug's entrance, expel the drugs, or use an alternate pathway that bypasses the drug's effects.

Choosing an Appropriate Drug Selection of an effective drug is guided by several factors. Among the most important considerations are the nature of the infectious agent, knowing whic… sensitive to, the possible side effec… and the medical condition of the pa…

(Drug Discovery) © Kathy Park Talaro; (Choosing an Appropriate Drug) © Copyright AB BIODISK 2008. Re-printed with permission of AB BIODISK



SCOPING OUT THE CHAPTER

We don't need to take a course in ornithology to be able to recognize the structure of a bird's wing and describe how it functions. And even when they're too far away for us to see them clearly, we can instantly know that a group of animals flying in a "V" formation is a flock of birds, not butterflies or bats. And though they are about as different as two animals could be, we all understand intuitively that a hummingbird and a turkey are related and should be grouped together. In this chapter we will gain the same type of familiarity with bacterial cells, by studying their structure, function, and evolutionary history.

Cellular Structure The chapter opens with a discussion of what makes up a prokaryotic cell. Beginning with external structures like flagella, moving to the fluid-mosaic barrier of the cell membrane, and finally to internal structures like inclusion bodies. Understanding the anatomy of a cell is key to understanding its biology.

Bacterial Shapes and Arrangements The cell wall and cytoskeleton of a bacterial cell are responsible for its shape, and correctly recognizing the shape of a cell is one of the first steps in determining its identity. The grouping of individual cells into more complex arrangements reveals a great deal about the manner in which a cell multiplies.

Classification and Unusual Bacteria The chapter continues by explaining the ways in which prokaryotic cells may be organized based on their evolutionary relationships. Finally, we introduce several examples of novel bacteria that thrive in boiling water (top left), extraordinarily high concentrations of salt (top right), or are so big that they threaten to redefine what it means to be a bacterium (bottom).

(left: top): *Source:* Louisa Howard/Dartmouth Electron Microscope Facility; (left: bottom): © Kwangshin Kim/Science Source; (middle: top-left): *Source:* Janice Carr/CDC; (middle: top-right): *Source:* Joyce Ayers/CDC; (middle: bottom): *Source:* Jeff Hageman, M.H.S./Janice Carr/CDC; (right: top-left): *Source:* Maryland Astrobiology Consortium, NASA and STScl; (right: top-right): *Source:* NASA Johnson Space Center/ISS007E8738/ (http://eol.jsc.nasa.gov); (right: bottom): © Heide N. Schulz/Max Planck Institue for Marine Microbiology

The Planning of a Student Success Learning Tool

Pedagogy designed for varied learning styles

The end-of-chapter material for the tenth 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 divided into two levels:

Level I. Knowledge and Comprehension
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 chapter's main 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 Form and Function of the Eukaryotic Cell: External Structures

A. The exterior configuration of eukaryotic cells is complex and displays numerous structures not found in prokaryotic cells. Biologists have accumulated much evidence that eukaryotic cells evolved through **endosymbiosis** between early prokaryotic cells.

B. Major external structural features include: appendages **(cilia, flagella), glycocalyx,** cell wall, and cytoplasmic (or cell) membrane.

5.3 Form and Function of the Eukaryotic Cell: Internal Structures

A. The internal structure of eukaryotic cells is compartmentalized into individual organelles.

B. Major **organelles** and internal structural features include: **nucleus, nucleolus, endoplasmic reticulum, Golgi complex, mitochondria, chloroplasts), ribosomes, cytoskeleton (microfilaments, microtubules).**

5.4 Eukaryotic-Prokaryotic Comparisons and Taxonomy of

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 pro
diseases?
a. hookworm
b. Chagas disease
c. leishmaniasis
d. a and b
e. b and c
f. all of these

Writing Challenge

Writing Challenge 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
Check Your Progress questions can also be used for writing-

1. Describe the anatomy and functions of each of the majo organelles.
2. Trace the synthesis of cell products, their processing, ar packaging through the organelle network.
3. a. What is the reproductive potential of molds in terms

Multiple-Choice Questions

Select the correct answer from the answers provided. For questions wit statement.

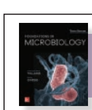
1. Both flagella and cilia are found primarily in
a. algae
b. protozoa
c. fungi
d. both b and c
2. Features of the nuclear envelope include
a. ribosomes

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, SmartBook allows for students to quiz themselves interactively using these questions.

End-of-Chapter Questions

Questions are divided into two levels.



Level I. Knowledge and Comprehension

These questions require a working knowledge of
and the ability to recall and understand the inform

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 a Student Success Learning Tool

Concept Mapping

An Introduction to Concept Mapping can be found on Connect.

Concept Mapping

On Connect you can find an Introduction to Concept Mapping that provides guidance for working with concept maps along with concept-mapping activities for this chapter.

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.

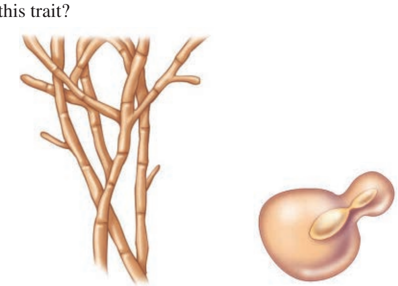
1. Explain the ways that mitochondria resemble rickettsias and chloroplasts resemble cyanobacteria.
2. Give the common name of a eukaryotic microbe that is unicellular, walled, nonphotosynthetic, nonmotile, and bud-forming.
3. How are the eukaryotic ribosomes and cell membranes different from those of 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

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.

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?



The Revision of a Student Success Learning Tool

Changes to Foundations in Microbiology, Tenth Edition

Overall Changes:

- A new feature "Scoping Out The Chapter" has been placed after the opening case studies. This page will give readers a descriptive pictorial guide for the main topics covered in chapters 1–17 and 26–27.
- Ten chapters (6, 7, 13, 19, 21, 22, 24, 25, 26, and 27) contain new case studies chosen for their relevance to major themes in the chapter.
- Approximately 175 new and replacement photographs have been included in the revision.
- Numerous images and figures have been revised and corrected.
- Clinical Connections boxes and side notes have a tinted screen added to set them off from the regular text. Several new Clinical Corrections boxes have been added.
- Coverage of diseases, statistics, and graphic data has been updated.
- Most chapters contain new links and quick searches for exploring topics on the internet.
- Special effort has been directed towards clarifying terms, wording, and definitions to improve understanding of more difficult concepts.

Chapter-Specific Changes:

Chapter 1

- The chapter opens with a new case study featuring microorganisms living in extreme habitats
- Epidemiology statistics have been updated throughout the chapter
- New information on the spread of chikungunya virus and Zika virus has been added
- Information concerning the ongoing pertussis epidemic has been updated
- Information on the link between microorganisms and chronic disease has been updated
- The topic of microbial evolution and classification has been updated

Chapter 2

- Discussions of the manner in which electron shells are filled and the importance of valence electrons to the formation of covalent bonds have been clarified
- The section on polymeric biomolecules (DNA, RNA, lipids, proteins, starches) has been clarified

Chapter 3

- New photos have been added to illustrate differences in resolution between light microscopes and electron microscopes
- New photos have been added to the discussions of fluorescence microscopy, electron microscopy, and selective and differential media

Chapter 4

- A new discussion and figure concerning bacterial microcompartments has been added.
- New photographs for a hyperthermophile and bacterial inclusion bodies

Chapter 5

- The case study concerning neglected tropical diseases (NTDs) has been updated to include the awarding of the 2015 Nobel Prize in Physiology or Medicine to scientists working in this area
- New tables summarize the function of structures within the eukaryotic cell
- New photos of the nucleus and mitochondria emphasize the importance of these organelles
- Update on *Pseudogymnoascus destructans,* the fungus responsible for white nose syndrome in bats

Chapter 6

- The chapter opens with a new case study focused on highly pathogenic avian influenza.
- The role of Adenovirus Ad-36 in weight gain and regulation of blood sugar levels has been updated.
- New photomicrograph of an Ebola virus budding from an infected cell

Chapter 7

- A new case study "A Creature of Habitat" describes the serious problem of cystic fibrosis and its connection with recurring *Pseudomonas* infections.
- New photographs for satellitism and an anaerobic growth chamber
- New information on biofilm formation

Chapter 8

- Addition of coenzymes to table on cofactors.
- Clarification of how the term fermentation is used under different contexts

Chapter 9

- Improved figure showing input by regulatory RNA
- Revised table on types of mutations.
- Updated box on regulatory, noncoding RNA, and riboswitches
- Improved consistency of figures for conjugation and transduction

Chapter 10

- Added details of newer DNA sequencing technologies
- Updated box on the human genome
- Revised tables on genetically-engineered animals
- New graph on genetically engineered crops
- Revised and updated Clinical Connections covering gene therapy
- The term DNA fingerprinting has been replaced with DNA profiling
- Figure on standardized DNA profiling has been revised
- Reorganized section on different uses of DNA profiling
- A note describing the gene editing technology of CRSPR has been added.

Chapter 11

- Updated case study on an outbreak of hepatitis C in a colonscopy clinic
- Integrated historical aspects of microbial control into main text and removed Making Connections box 11.1.
- New Clinical Connections box discusses the sterilization of reusable medical devices
- Revised the box on use of triclosan, including new FDA ruling

Chapter 12

- Integrated Making connections 12.2 on discovery of drugs into main chapter
- Added a new figure on the chemical synthesis of penicillin drugs
- Included new categories of antibacterial and antiviral drugs
- Updated drug resistance box and added a new figure showing carbapenem-resistant enterobacteriaceae (CRE)

Chapter 13

- New case study "Fatal Filaments from Far Away Africa" that covers the Ebola epidemic in Africa and its spread to the United States.
- Introduced new information on the importance of the microbiome to general human physiology
- Coverage of the relationship of the placental microbiome to infant development and the development of the intestinal microbiome in newborns.
- New surveillance figures for HIV infection, pertussis, and Ebola fever.
- Updated figure on healthcare associated infections (HAI); replacing use of nosocomial infections with the more commonly used HAI

The **Effort** of a Student Success Learning Tool

- New visual challenge figures to differentiate among different epidemiological patterns for diseases

Chapter 14

- Added new information on the hygiene hypothesis
- Clarified figure on the actions of complement
- Removed discussion of fever from Clinical Connections box and integrated it into text

Chapter 15

- Reorganized the order of introduction of T cell and B cell actions and functions; T cells now are covered first, followed by B cells.
- Revised figure 15.1 to align with new order of coverage.
- Added side note to focus on the functions of T regulatory cells with new information on biologic drugs based on this type of T cell
- Updated the list of monoclonal antibody-based drugs and currently-approved vaccine schedules.
- Coverage of the breast microbiome and the role breast milk has in the development of the immune systems of infants.

Chapter 16

- Revised allergen count figure
- New photographs of atopic and contact dermatitis
- New photograph of blood typing
- New photograph of rheumatoid arthritis
- Illustration of child with velocardiofacial (DiGeorge) syndrome

Chapter 17

- Updated box on point-of-care testing
- New example of the direct fluorescent antibody test
- Replacement figure for rapid identification testing
- New examples of serological test results

Chapter 18

- New electron photomicrograph of methicillin-resistant *Staphylococcus aureus* has been added
- New photos of erysipelas and limb necrosis due to meningococcemia
- Updated recommendations for treatment of bacterial infections
- Updated statistics on the prevalence of sexually transmitted diseases
- The discussion of meningococcemia and meningitis has been clarified

Chapter 19

- The chapter opens with a new case study concerning *Listeria monocytogenes*
- New photomicrographs of *Bacillus anthracis*, *Corynebacterium diphtheriae*, and fluorescently labeled *Mycobacterium tuberculosis* have been added
- New photographs for myonecrosis, erysipeloid, the Mantoux skin test for tuberculosis, paucibacillary leprosy, multibacillary leprosy, fish tank granuloma, and actinomycosis
- Expanded and updated discussion of the use of fecal microbiota transplants as a treatment of *C-difficile* infection
- New electron micrograph of *Mycobacterium tuberculosis*, updated worldwide statistics for tuberculosis, and updated treatment recommendations for both active and latent tuberculosis
- Updated classification of leprosy to match WHO standards

Chapter 20

- New photomicrograph of *Pseudomonas aeruginosa* and new photo of cutaneous *Pseudomonas* infection
- Updated treatment recommendations for *Pseudomonas* infection, *Brucellosis,* and *Tularemia*
- New information on pertactin-deficient strains of *Bordetella pertussis*
- Updated discussion of *E. coli* pathotypes
- New section on Carbepenem-resistant Enterobacteriaceae infections
- New section on naming conventions in *Salmonella*

Chapter 21

- Chapter opens with a new case study on Q fever and live cell transplantation
- New photographs of *Coxiella burnetti*, *Treponema pallidum*, *Borrelia burgdorferi*, *Vibrio cholera*, *Campylobacter jejuni*, *Orienta tsutsugamushi*, and *lxodes scapularis*
- Updated statistics on syphilis
- New treatment recommendations for cholera
- New photos of dental caries and oral bacteria

Chapter 22

- Case study has been updated to include the latest facts concerning the fungal meningitis outbreak connected to the New England Compounding Center
- Updates on antifungal drugs and epidemiological statistics
- New photographs of cutaneous blastomycosis, *Tinea pedis, Aspergillus,* and aspergillosis
- Reclassification of zygomycosis as mucormycosis

Chapter 23

- Updated drug recommendations for parasitic diseases
- New discussion on genetically engineered mosquitoes resistant to *Plasmodium sp.*
- New feature on Carlos Chagas and his importance to the field of parasitology
- The latest information about phase 3/4 trials of malaria vaccine RTS,S

Chapter 24

- The chapter begins with a new case study concerning unusual varicella zoster virus transmission
- New photos of herpes simplex type 1, neonatal herpes, and lymphocytes infected with Epstein-Barr virus
- Updated recommendations for treatment of neonatal herpes
- Update on treatment and prevention of HPV

Chapter 25

- New case study on measles and subacute sclerosing panencephalitis
- Updates include information on the Ebola outbreak of 2014–2016, the ongoing Zika virus outbreak, and widespread outbreaks of chikungunya virus
- Updated information on influenza vaccines and new chemotherapeutic treatments for influenza
- New information on the measles outbreak of 2015 along with discussion and references to online documentaries about vaccine skepticism
- Distribution maps for *Aedes* mosquitoes, the vector of dengue, chikungunya, and Zika viruses
- Feature on the *Aedes* mosquito
- Information about the recently approved vaccine to prevent dengue fever
- Updates on treatment strategies for HIV, including the use of pre-exposure prophylaxis (PrEP)

Chapter 26

- New case study on drinking water contamination as a result of harmful algae blooms
- New photos of *Rhizobium* root nodules and mycorrhizae
- New discussion concerning fracking as a potential contaminant of groundwater

Chapter 27

- New case study concerning three separate outbreaks of food poisoning

Acknowledgments

This edition marks the 24th anniversary of the first publication of Foundations in 1993. Looking back over the previous nine 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 10th 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 product developer Mandy Clark, keeping us on track and providing much needed moral support. We also appreciate the insights and contributions of brand manager Marija Magner and marketing manager Jessica Cannavo. Our project manager Jayne Klein has been an experienced and knowledgeable guide through the intricacies of a digital-style revision.

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 Wendy Nelson. After poring over 800 plus pages of text in a few months, she may feel like she has taken a crash course in microbiology.

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

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, and 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?"

Right from the first, you need to be guided by how your instructor has organized your course. Because there is more information than could be covered in one semester or quarter, your instructor will select what he or she wants to emphasize and will construct reading assignments and a study outline 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. Mainly, you will want to focus on more than just reading alone to gather the most important points from a chapter. Try to incorporate writing, drawing simple diagrams, and discussion or study with others. You must attend lecture and laboratory sessions to listen to your instructors or teaching assistants explain the material. You can rewrite the notes you've taken during lecture, or outline them 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. With these kinds of interactions, you will move beyond simple rote memorization of words and will come to *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 helps to track what you know, pinpoint what you don't know, and creates personalized questions 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 repetition and experience are the most effective ways to acquire knowledge.

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 such knowledge has been in their professions and everyday life.

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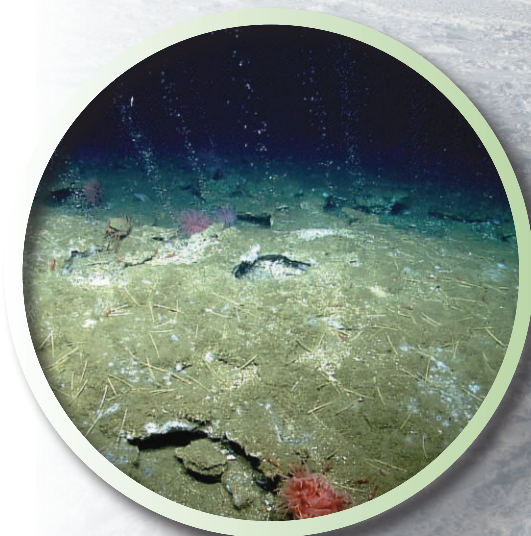
CHAPTER 1

The Main Themes of Microbiology



Streams of methane bubbles rise from the seafloor, the product of microscopic organisms adapted to the extreme environment of the deep ocean.
Source: NOAA Okeanos Explorer Program, 2013 ROV Shakedown and Field Trials in the U.S. Atlantic Canyons

A microbial ecologist carries a water sample from subglacial Lake Whillans, 640 kilometers from the South Pole.
© JT Thomas

CASE STUDY Part 1 Microbes Find A Way

A frozen white wasteland, a toxic soup, a lunar landscape. Three fairly common descriptions of an environment so harsh—cold, toxic, or lacking nutrients—that no life can survive. Lake Whillans, a small, shallow lake trapped beneath half a mile of ice, certainly fits that description. Located 640 kilometers from the South Pole, Lake Whillans is completely encased in ice and sits at a slant, pressed against the side of a hill far below the icy surface. As heat from the core of the Earth melts the bottom of the Antarctic ice sheet, a few milliliters of liquid water are added to the lake each year.

Subglacial lakes like Lake Whillans were discovered only in the late 1990s when ice-penetrating radar and satellite measurements allowed researchers to see through the dense ice sheets that cover the polar regions of the planet. The next phase of the project was—as has been the case as long as humans have been exploring their environments—to determine what, if anything, lived in the newly discovered area. Although the immediate instinct would be to drill through the ice and sample the water in the lake, **microbial ecologists** realized that sampling Lake Whillans was not terribly different from performing surgery on a human patient; **aseptic techniques** would have to be followed so that external microbes were not allowed to contaminate the lake. Drilling equipment was **sterilized** using a combination of ultraviolet light and hydrogen peroxide, the same techniques routinely used in hospitals and laboratories, and the water used to bore through the ice was filtered to remove even the smallest microorganisms. When the drill penetrated the last of the ice, it entered the lake, which at −0.5°C was several degrees warmer than the Antarctic surface.

> "It's the first time we've gotten a real insight into what organisms might live beneath the Antarctic continent."
>
> **David Pearce, a microbiologist at Northumbria University, UK**

Over the next few days, until the drilling hole froze shut, scientists and graduate students collected 30 liters of water and several sediment samples from the lake. Study of those samples, which continues today, reveals that Lake Whillans hosts a vibrant ecosystem. **DNA analysis** revealed nearly 4,000 different **microbial species,** and each milliliter of lake water contained more than 130,000 cells, comparable to what one finds in the deepest oceans. The biggest difference between life in Lake Whillans and ecosystems found on the surface of the planet is the lack of sunlight. In terrestrial lakes **photosynthetic microorganisms** use the energy in sunlight to convert dissolved carbon dioxide into sugars. Because sunlight can't penetrate the half mile of ice covering Lake Whillans, many of the microbes in the lake derive energy from the oxidation of iron, sulfur, or ammonium compounds, a strategy used by some deep-sea bacteria. If it turns out, as many scientists believe, that the microorganisms in Lake Whillans supply minerals and nutrients to the surrounding ocean, then this small, dark, cold, invisible lake may have a tremendous effect on the ecosystem surrounding it. Not bad for a frozen wasteland.

- *One of the environmental pressures microorganisms from Lake Whillans had to adapt to was the ability to grow in very cold temperatures. What were several other environmental challenges these microbes faced?*
- *What fields of microbiology were used to initially study these microbes, and what fields could be involved in the further study of the isolated cells?*

To continue this Case Study, go to Case Study Part 2 at the end of the chapter.

SCOPING OUT THE CHAPTER

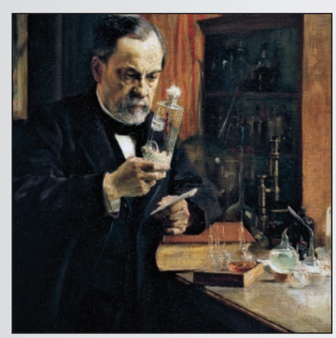
Microbiology is sometimes regarded as an esoteric science, concerned primarily with keeping the milk fresh and getting everyone to wash their hands. In fact, microbiology encompasses a number of interrelated disciplines, a rich history, and more organisms than any other branch of biology. In this chapter you'll get a quick tour of the field.

The Fields of Microbiology
Not every microbiologist works in a lab. Making cheese, wine and bread all rely on a knowledge of microbiology.

The Power of Microbiology
The vats here contain algae that are producing oil through photosynthesis, a potentially endless source of clean energy.

The Evolution of Microorganisms
All life on Earth has evolved from simple microbial cells. Evolutionary trees display the relationship between simpler and more complex organisms.

The Organisms of Microbiology
The vast majority of microorganisms pose no risk to humans. Some however, like certain strains of the bacterium *Staphylococcus aureus,* not only cause severe disease, but are resistant to almost all the drugs commonly used to fight them.



The History of Microbiology
The period from 1850 to 1950 is sometimes known as the **Golden Age of Microbiology**, when people like Louis Pasteur invented the very science of microbiology itself. The recent advent of powerful molecular biology techniques has caused many scientists to view the current era as a second Golden Age.

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 fields 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 from our sight by 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

* *ubiquitous* (yoo-bik′-wih-tis) L. *ubique,* everywhere and *ous,* having. Being, or seeming to be, everywhere at the same time.

natural habitats and most of those that have been created by humans. As scientists continue to explore remote and unusual environments, the one kind of entity they always find is microbes. These 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.

The specialty professions of microbiology include:

- 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 diseases associated with them;
- nurse epidemiologists, who analyze the occurrence of infectious diseases in hospitals; and
- astrobiologists, who study the possibilities of organisms in space (see the Case Study for chapter 2).

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).

* *microscopic* (my″-kroh-skaw′-pik) Gr. *mikros,* small, and *scopein,* to see.
* *microbe* (my′-krohb) Gr. *mikros,* small, and *bios,* life.

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 and 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 "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. Having existed for eons, they are absolutely essential for maintaining the planet's life-giving characteristics.

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

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.
Source: Photo by Scott Bauer/USDA

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.
© Henry Bortman

C. Biotechnology and Industrial Microbiology

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.
Source: Lawrence Berkeley National Laboratory

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.
Source: James Gathany/CDC

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.
Source: Biological and Environmental Research Information System, Oak Ridge National Laboratory. Sponsored by the U.S. Department of Energy Biological and Environmental Research Program.

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.
Source: Photo by Black Star/Steve Yeater for FDA

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.
Source: Photo by Keith Weller/USDA

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).
Source: James Gathany/CDC

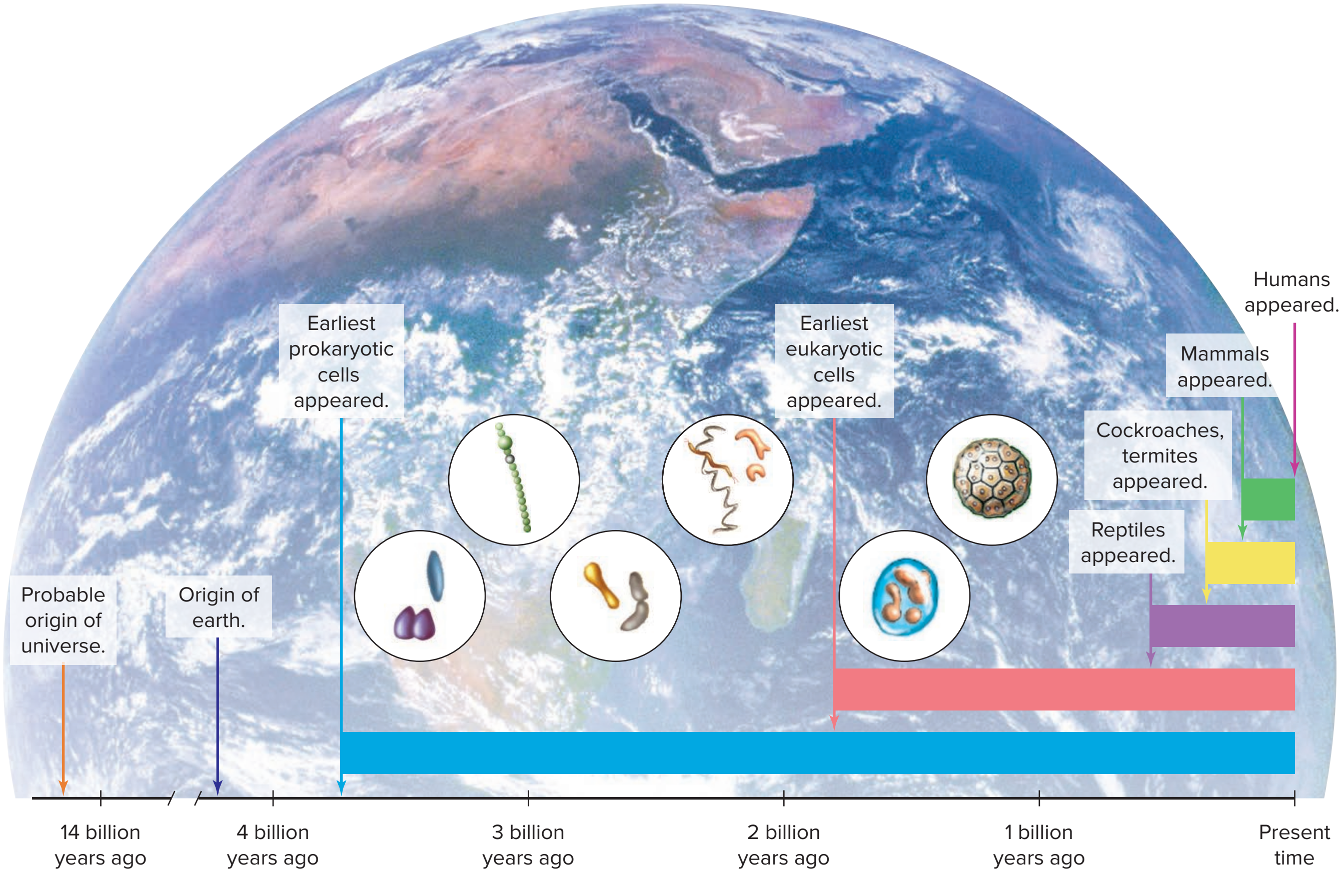


Figure 1.1 Evolutionary time line. The first simple prokaryotes appeared on earth approximately 3.5 billion years ago, and the first eukaryotes arose about 2 billion years ago. Although these appearances seem abrupt, hundreds of millions of years of earth's history passed while they were evolving to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

The Cellular Organization of Microorganisms

As a general rule, prokaryotic cells are smaller than eukaryotic cells, and in addition to lacking a nucleus, 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 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,

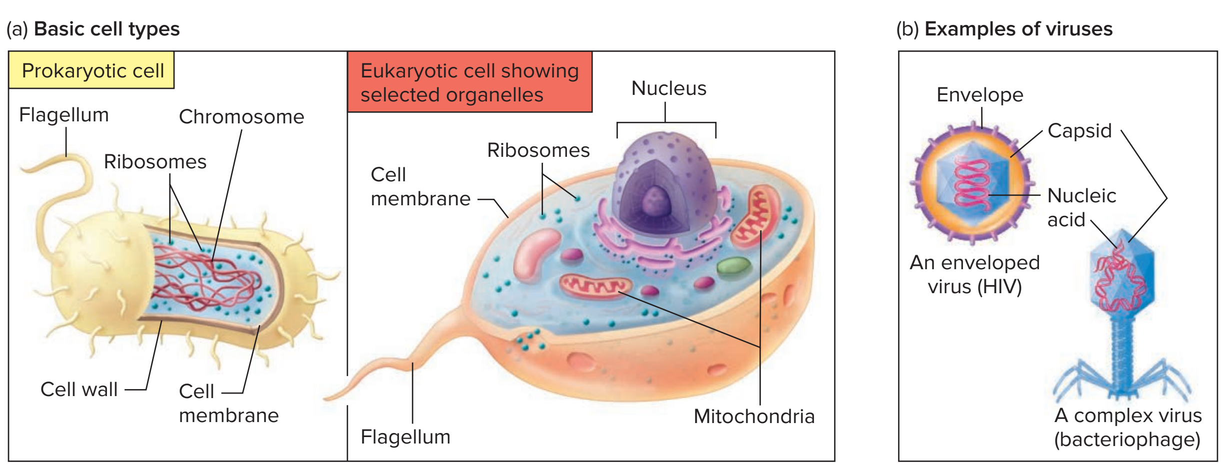
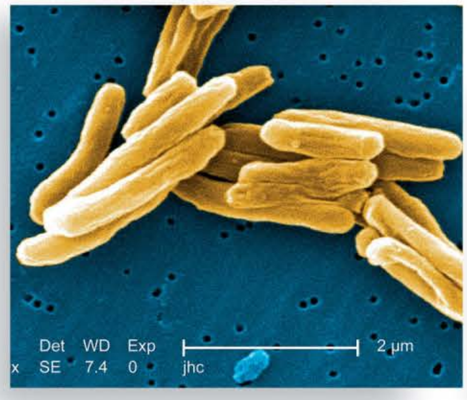
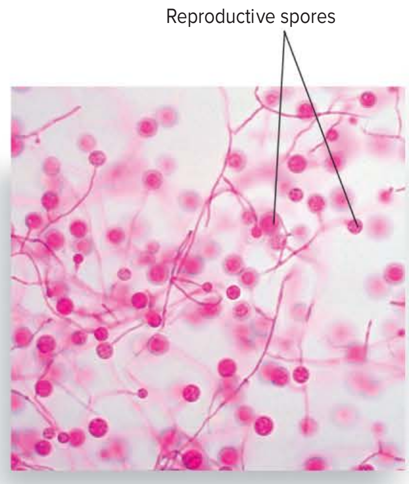


Figure 1.2 Basic structure of cells and viruses. (a) Comparison of a prokaryotic cell and a eukaryotic cell. **(b)** Two examples of viruses. These cell types and viruses are discussed in more detail in chapters 4, 5, and 6.

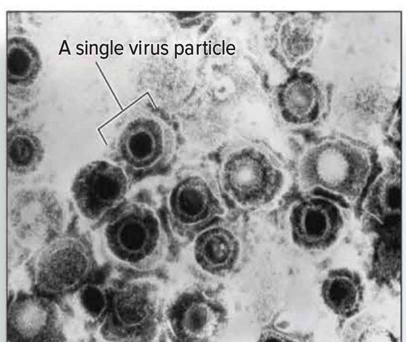


Bacteria: *Mycobacterium tuberculosis,* a rod-shaped cell (15,500x).



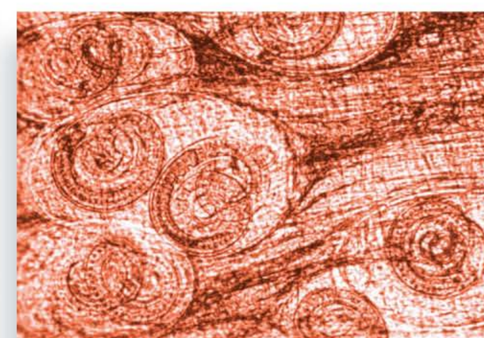
Fungi: *Histoplasma capsulatum*, with lollipop-like reproductive structures (750x). This agent is the cause of Ohio Valley fever.

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).



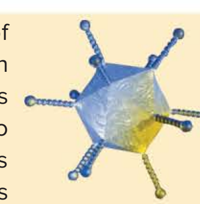
Helminths: Roundworms of *Trichinella spiralis* coiled in the muscle of a host (250x). This worm causes trichinellosis.

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. (bacteria): *Source:* Janice Carr/CDC; (fungi): *Source:* Dr. Libero Ajello/CDC; (algae): © Charles Krebs Photography; (virus): *Source:* CDC; (protozoa): *Source:* National Human Genome Research Institute; (helminths): *Source:* CDC

and they 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. Not all members of these last two groups are microscopic, but certain members are still included in the study of microbiology 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?

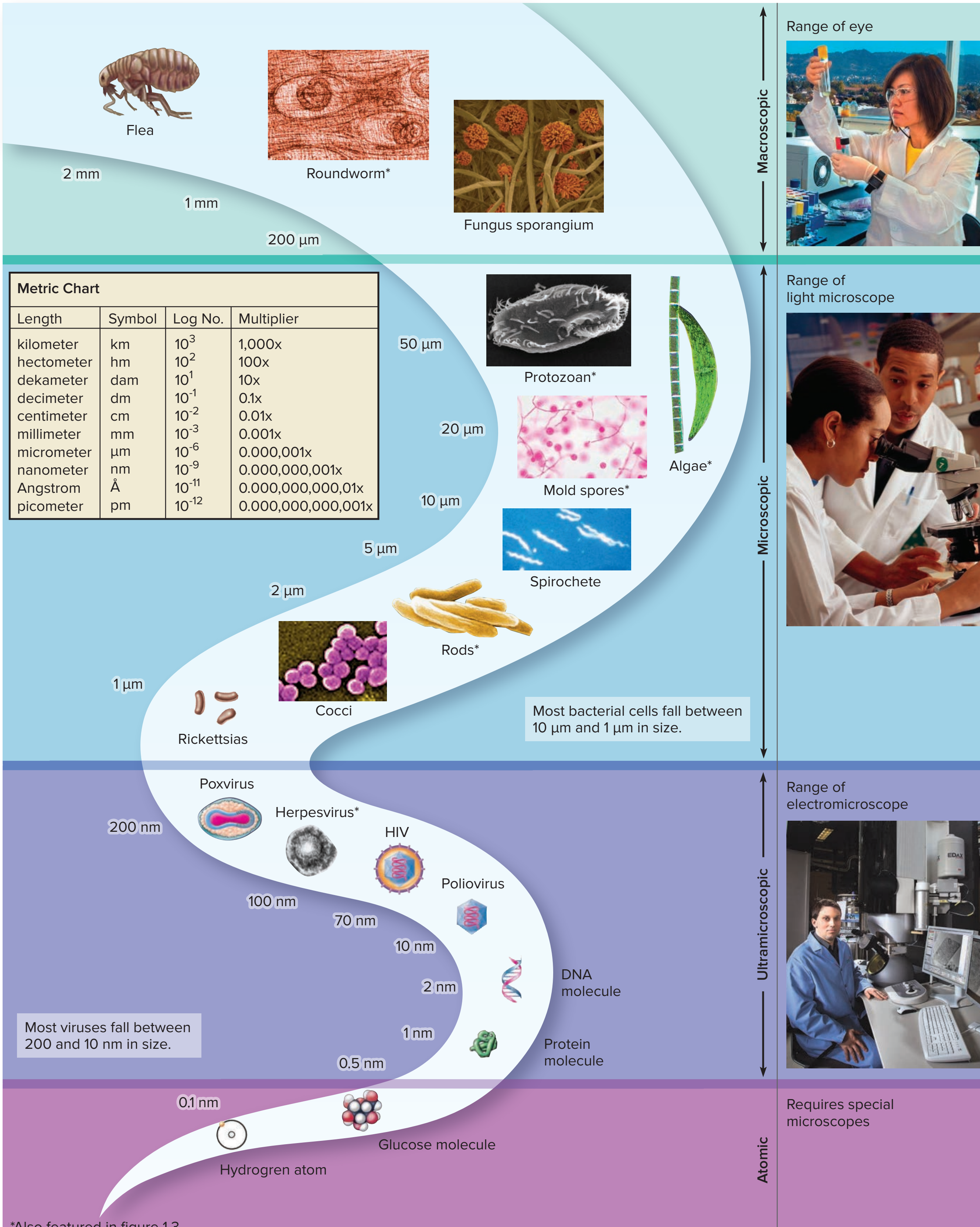
Viruses are considered one type of microbe because they are microscopic and can cause infections and disease, but they are not cells. They are small particles that exist at a level of complexity somewhere between large molecules and cells (see figure 1.4). Viruses are much simpler than cells; they are 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 can 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



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 variations 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.
(roundworm): *Source:* CDC; (fungus): © Dennis Kunkel Microscopy, Inc./Phototake; (protozoan): *Source:* National Human Genome Research Institute; (algae): © Charles Krebs Photography; (mold spores): Dr. Libero Ajello/CDC; (spirochete): *Source:* CDC; (rods, cocci): *Source:* Janice Carr/CDC; (herpesvirus): *Source:* CDC; (range of eye): *Source:* Berkeley Lab - Roy Kaltschmidt, photographer; (range of light microscope): *Source:* Rhoda Baer (photographer)/National Cancer Institute; (range of electromicroscope): *Source:* Pacific Northwest National Laboratory

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 all of their roles, but it is likely they are vital components of the structure and function of these ecosystems.

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 in 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.

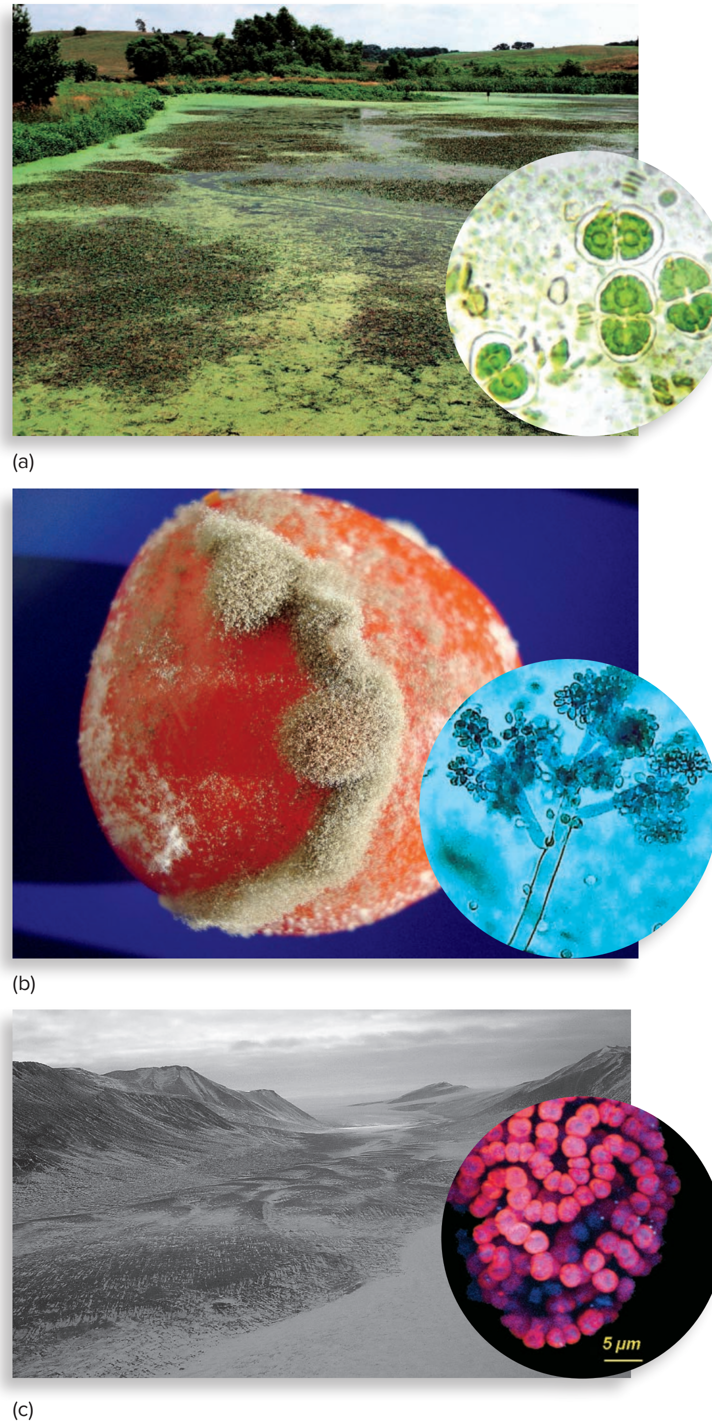


Figure 1.5 A microscopic wonderland. (a) A summer pond is heavily laden with surface scum that reveals several different types of green algae called desmids (600×). **(b)** A rotting tomato being invaded by a fuzzy forest of mold. The fungus is *Botrytis,* a common decomposer of tomatoes and grapes (250×). **(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. Like the example discussed in the chapter-opening case study, this environment may serve as a model for what may one day be discovered on other planets. (a): *Source:* Photo by Lynn Betts, USDA Natural Resources Conservation Service; (a, inset) © Stephen Sharnoff/National Geographic Creative; (b & b, inset): © Kathy Park Talaro; (c) © Peter Doran/University of Illinois, Chicago; (c, inset) Image courtesy of the Priscu Research Group, Montana State University, Bozeman

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