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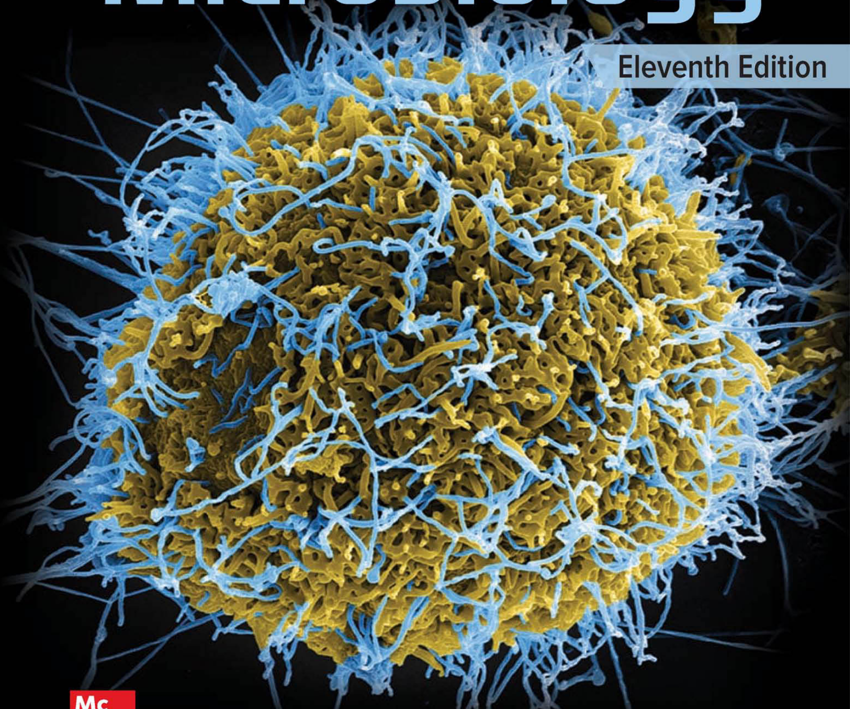
# *Talaro's* Foundations in Microbiology

Eleventh Edition



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Barry Chess

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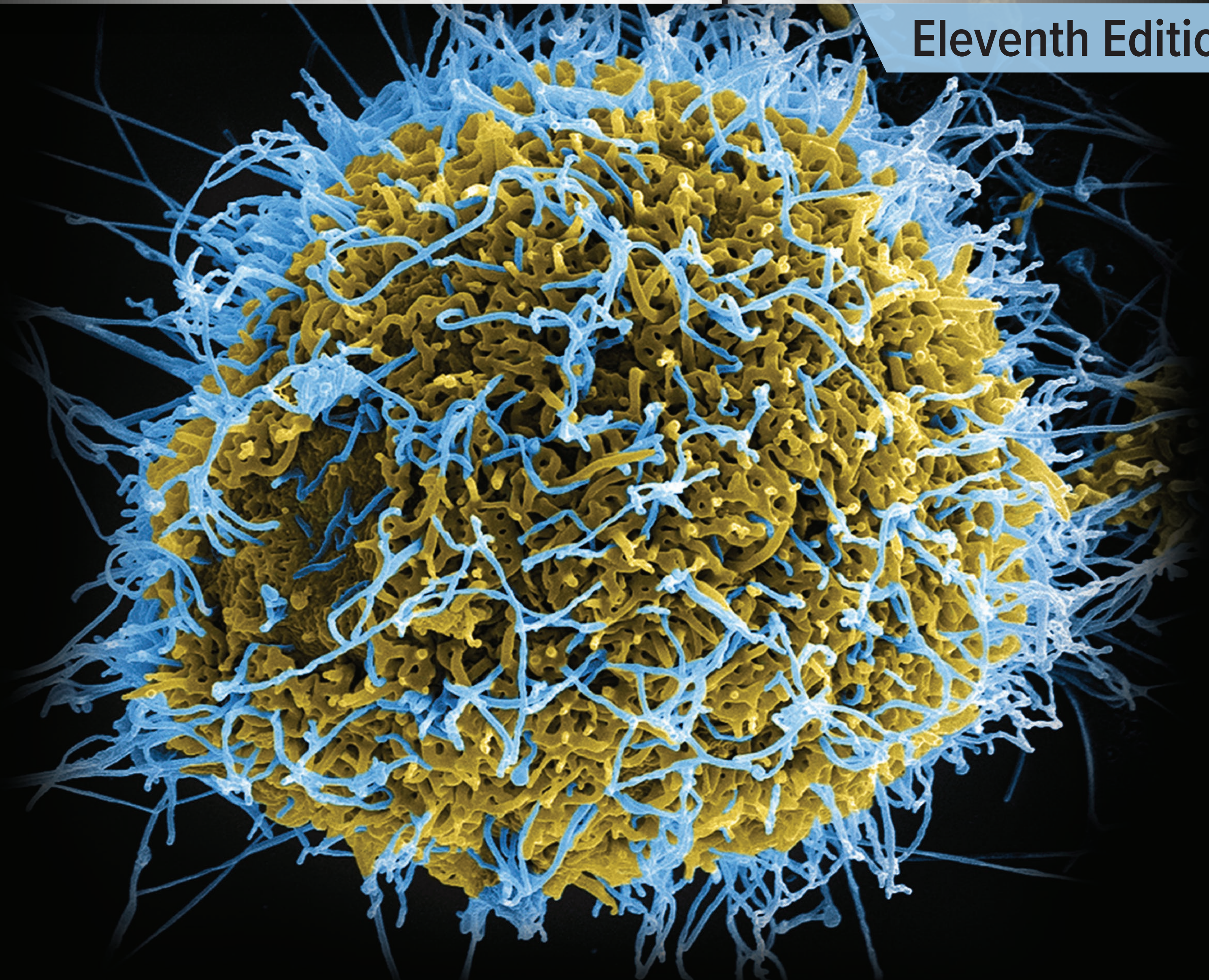
# *Talaro's* Foundations in Microbiology

## Basic Principles

**Eleventh Edition**



Mc Graw Hill

**Barry Chess**

FOUNDATIONS IN MICROBIOLOGY BASIC PRINCIPLES



This book is printed on acid-free paper.
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Cover Image: *Filamentous Ebola virus particles (colored blue) budding from a chronically-infected VERO E6 cell (colored yellow). Callista Images/Getty Images*



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# Brief Contents



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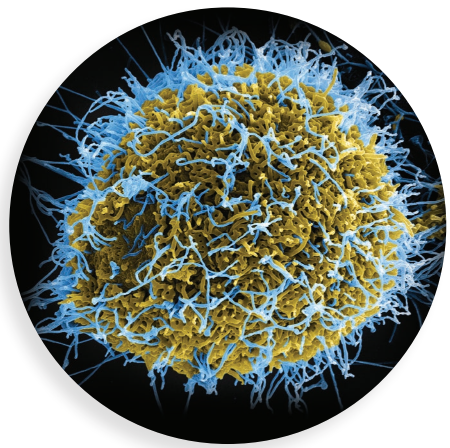
# About the Author

**Barry Chess** has taught microbiology at Pasadena City College for more than 20 years. Prior to that, while studying at the California State University and the University of California, he conducted research into the expression of genes involved in the development of muscle and bone.

Barry Chess

At PCC, beyond his usual presence in the microbiology laboratory and lecture hall, Barry has taught majors and non-majors biology, developed a course in human genetics, helped to found a biotechnology program on campus, and regularly supervises students completing independent research projects in the life sciences. Of late, his interests focus on innovative methods of teaching that lead to greater student success. He has written and reviewed cases for the National Center for Case Study Teaching in Science and contributed to the book *Science Stories You Can Count On: 51 Case Studies with Quantitative Reasoning in Biology*. Barry has presented papers and talks on the effective use of case studies in the classroom, the use of digital tools to enhance learning, and for several years served as a scientific advisor for the American Film Institute.

In addition to *Foundations in Microbiology*, Barry is the author of *Laboratory Applications in Microbiology, A Case Study Approach*, now in its fourth edition. He is a member of the American Association for the Advancement of Science, the American Society for Microbiology, and the Skeptics Society. When not teaching or writing, he spends as much time as possible with water; skiing atop it in winter and diving beneath it in summer. Barry was profiled in the book *What Scientists Actually Do*, where he was illustrated as a young girl with pigtails, about to stick a fork into an electrical outlet.



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The eleventh edition marks the first time that Kathy Talaro has been absent from this book. In creating *Foundations in Microbiology* she revolutionized how we teach the subject, and every other text in the field uses methods, ideas, and examples that Kathy pioneered. Personally, Kathy has been a friend and mentor for more than 20 years. By stepping away, Kathy will once again have the opportunity to wonder at the microbes around her, without having to simultaneously worry about what needs to be cut from Chapter 17.

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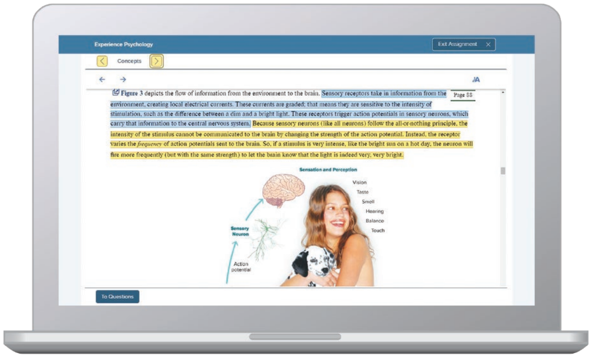

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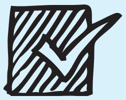

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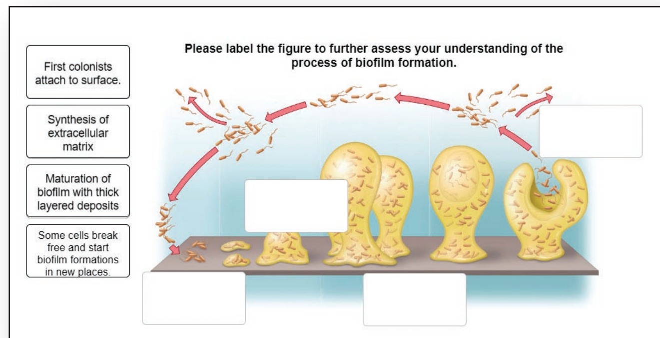


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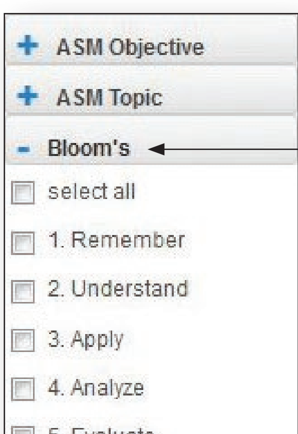


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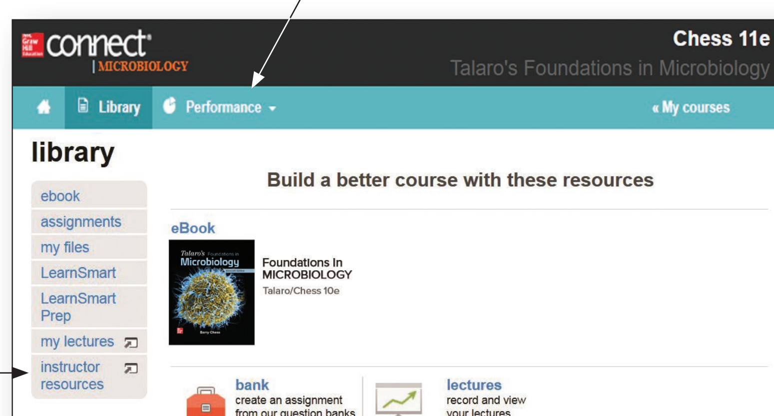


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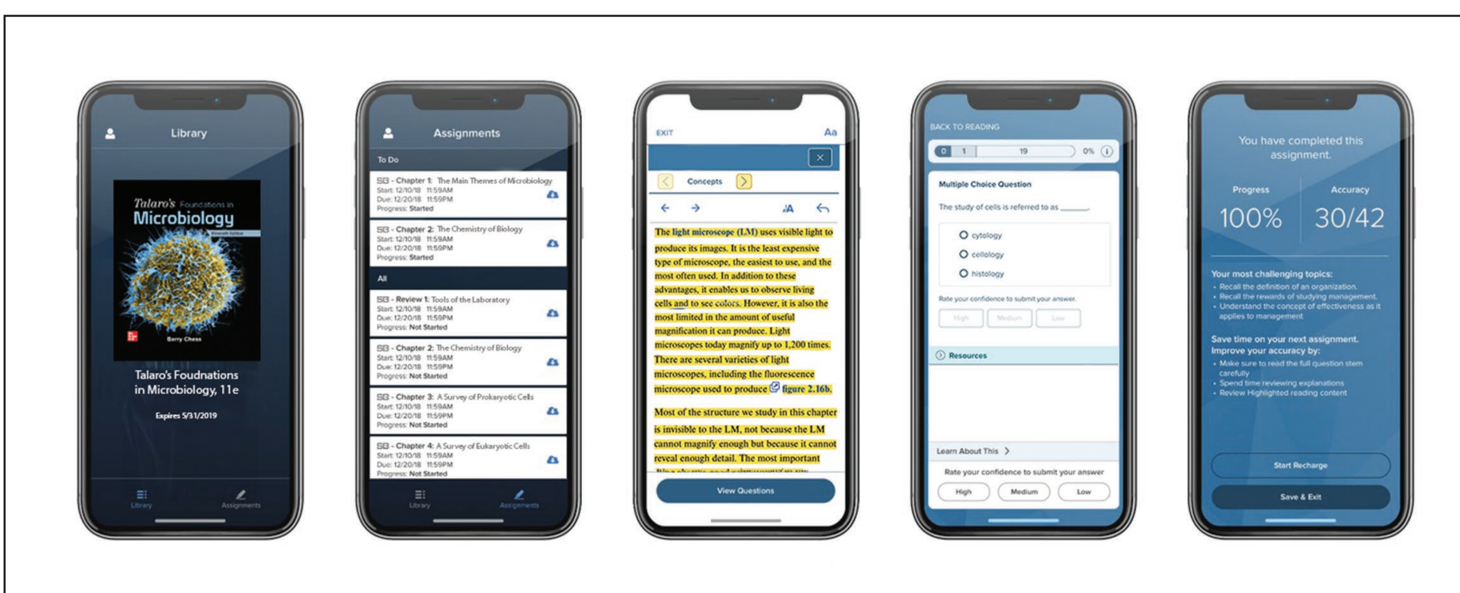
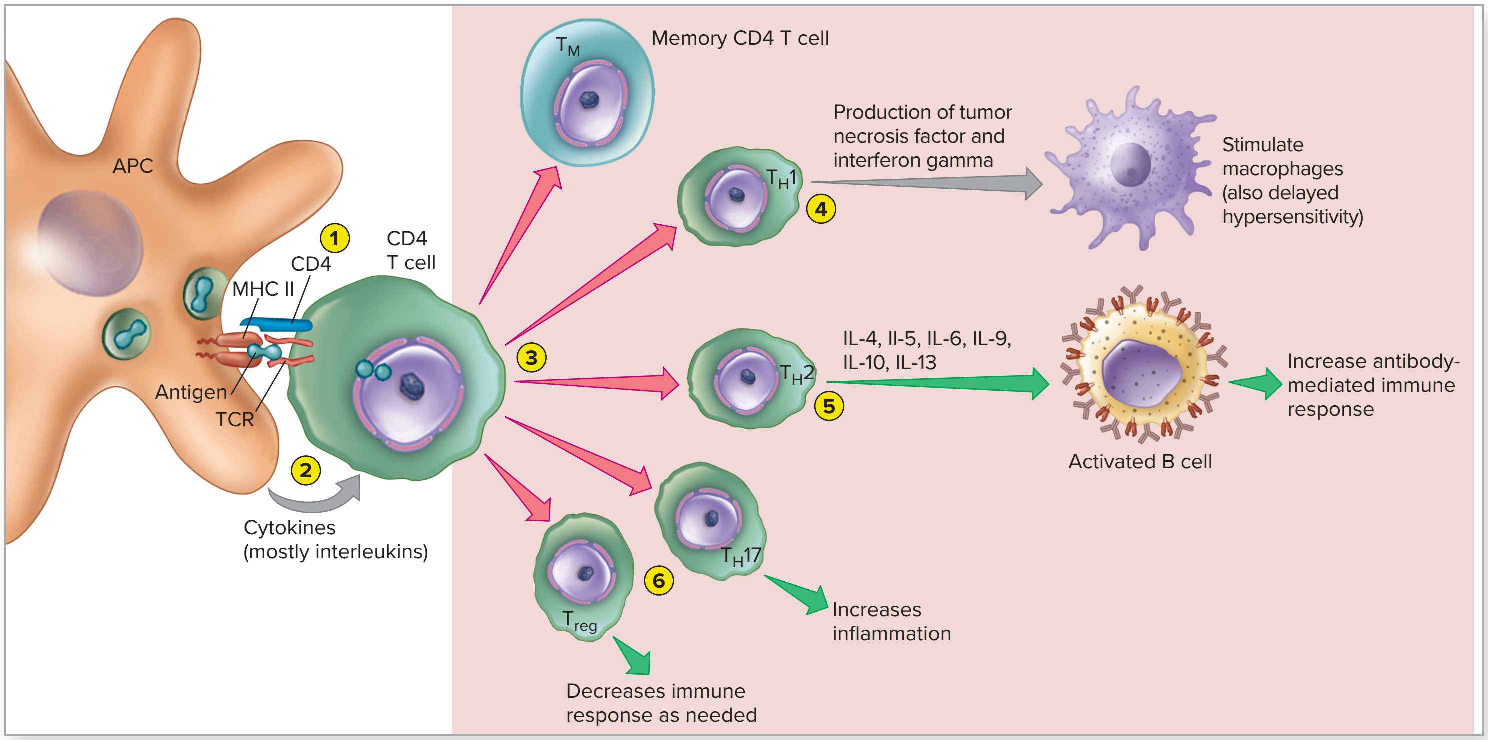


# Designed for Today's Students

## Art and organization of content make this book unique

You always hope that the current revision will be easier, that after 11 editions and 30 years you've finally managed to create the perfect book. But, of course, that's never the case. Crafting a truly useful learning tool for students takes time and dedication. Every line of text and every piece of art is scrutinized for instructional usefulness, placement, and pedagogy, and then reexamined with each revision. In this eleventh edition, the author has gone through the book page by page, with more depth than ever before, to make sure it maintains its instructional quality, superior art program, currency, and engaging 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 manner that students can understand. The eleventh edition continues to meet these goals with the most digitally integrated, up-to-date, and pedagogically important revision yet. More than a compendium of facts, figures, and photographs, *Foundations in Microbiology* tells a story of microorganisms, of people, and of the myriad ways in which they interact.

An effective 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 component parts; and provide explanations that are clear, concise, and correctly targeted to the reader, with pedagogical tools that help all types of learners. Hopefully, the time and effort put into this revision shows, so that when the pieces come together, the result is an expertly crafted learning tool—a story of the microbial world.




A strong art program is a defining quality of an effective textbook. Complex biological processes can be disassembled into their component parts, allowing understanding to take place one step at a time. Working closely with scientific illustrators, Barry Chess ensures that *Foundations in Microbiology* has an art program that allows difficult concepts to come to life.

# Structured to Promote Critical Thinking

## Chapter-Opening Case Studies

Each chapter opens with a two-page introduction. On the left is a synopsis of the chapter's contents, while the right side contains the first part of the Case Study, which has been carefully chosen to exhibit microbiology in real-world situations. Line art and micrographs are all part of the chapter-opening pages to help students see the big picture and grasp the relevance of the material they're about to study. Questions appearing after the chapter opener serve as prompts to the most important aspects of the case, providing students with touchstones to lean on as they learn. The chapter concludes with the second part of the Case Study, which resolves the microbiological (and occasionally social, political, and economic) aspects of the case. Once again, questions follow, helping students to reinforce their newfound knowledge, and use it to develop a more inquisitive view of the broader world.

**CASE STUDY Part 1** When a Body Can't Get Out of Its Own Way

Certain combinations of **signs** and **symptoms** are guaranteed to garner the attention of an emergency room physician, because they signal a serious, **emergent situation.** So, when a young woman seen by emergency room doctors displayed **tachypenea** (rapid breathing), a depressed level of consciousness, and **fever,** she was immediately admitted to the hospital for further examination. She also exhibited low blood pressure, had not passed any urine that day, and had a blueish tinge to her fingers and toes, a clinical presentation compatible with **sepsis.** Sepsis is a serious complication of infection that occurs when chemicals released by the body trigger an overwhelming inflammatory response. Without rapid, aggressive treatment, sepsis can quickly lead to death.

Laboratory tests were also consistent with sepsis, as the patient had a **low platelet count** and a decreased number of infection-fighting **leukocytes.** Elevated levels of C-reactive protein indicated widespread inflammation throughout the body, while blood tests showed damage to the liver and kidneys, along with intravascular coagulation. Sepsis was causing her body to shut down.

The patient, though only 15 years old, was no stranger to the hospital. She had been diagnosed with **systemic lupus erythematosus (SLE,** or simply lupus) at the age of 6 and had an extensive medical history. Lupus is an autoimmune disorder in which the body's immune system attacks itself by producing **antibodies** against the nuclei of its own cells. **Inflammation** due to lupus can affect the skin, joints, kidneys, liver, heart, and lungs, with symptoms ranging from mild to severe, and fluctuating greatly over time. In less than 9 years, the patient had already experienced nephritis, pancreatitis, hemolytic anemia, and arterial hypertension, all due to a particularly aggressive form of the disease. Her lupus was being treated with corticosteroids along with multiple **immunosuppressive drugs,** including methotrexate and cyclophosphamide. She was last seen at the hospital 3 months previously, where she displayed no clinical manifestations of SLE.

A chest X-ray was unremarkable, while a computed tomography (CT) scan revealed sinusitis, likely not enough to cause the symptoms seen in the patient. *Streptococcus pneumoniae* was cultured from both the blood, indicating a **systemic infection,** and cerebrospinal fluid, indicating **meningitis.** *Streptococcus pneumoniae* is a gram-positive, heavily **encapsulated** bacterium, commonly responsible for infections of the sinuses, lungs, blood, and meninges. An MRI (magnetic resonance imaging) scan was performed, the results of which were remarkable not for what was seen, but for what was absent. The patient did not have a spleen.

- *Inflammation is normally part of what line of defense?*
- *If the immune system functioned properly, what type of white blood cell would be increased in number in this case?*

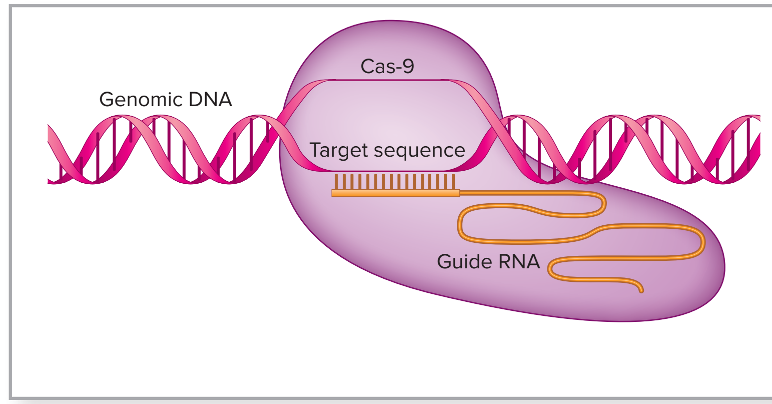
*To continue the Case Study, go to Case Study Part 2 at the end of the chapter.*

Plush Studios/Blend Images LLC

# Illustrated to Increase Understanding

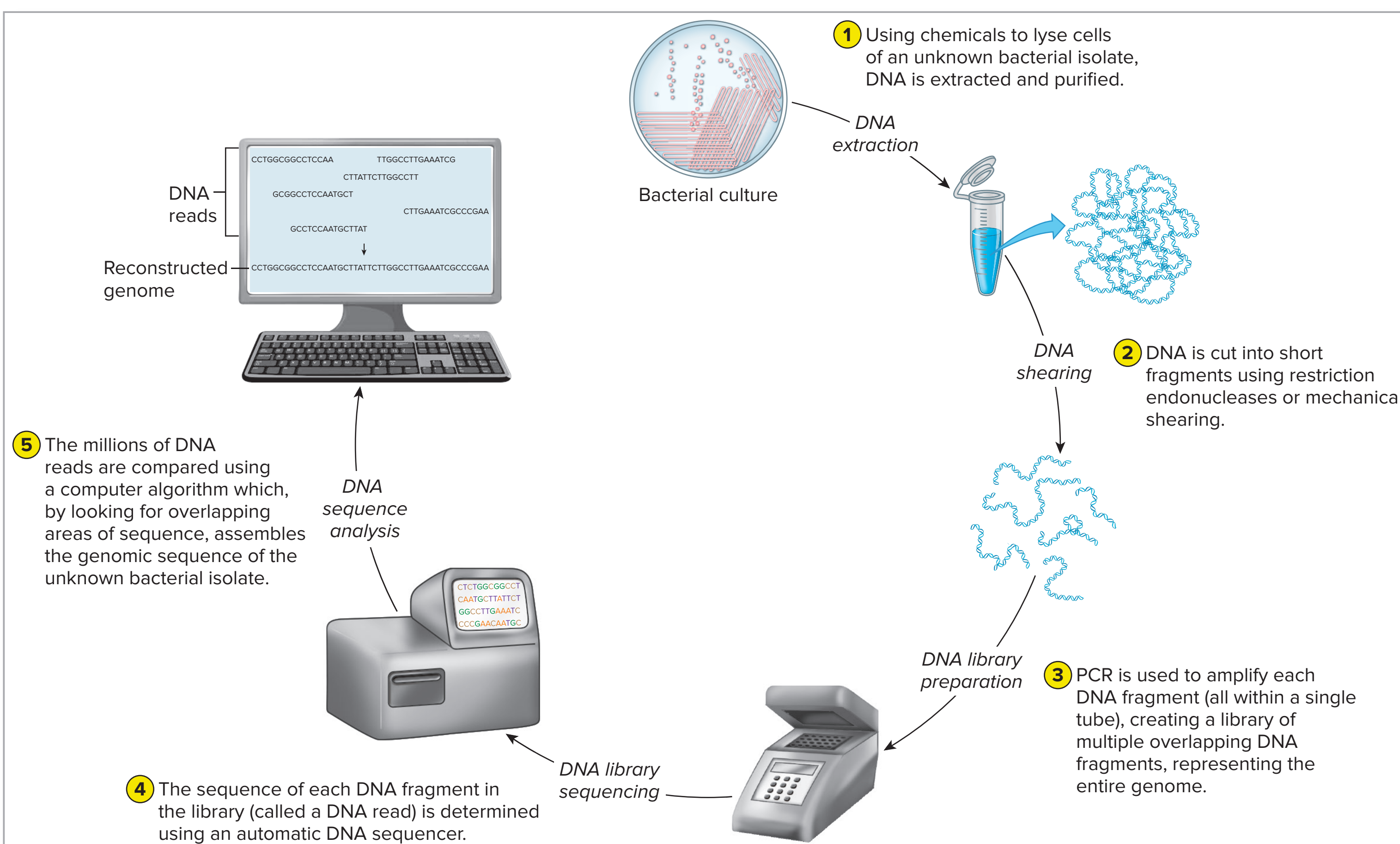
## The author’s experience and talent transform difficult concepts

Truly instructional artwork has always been a hallmark feature of *Foundations in Microbiology*, and the eleventh edition of the book continues to set the standard. Common sense, backed by many decades of research, have shown that when abstract concepts are explained using scientifically accurate illustrations, understanding is increased. 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.

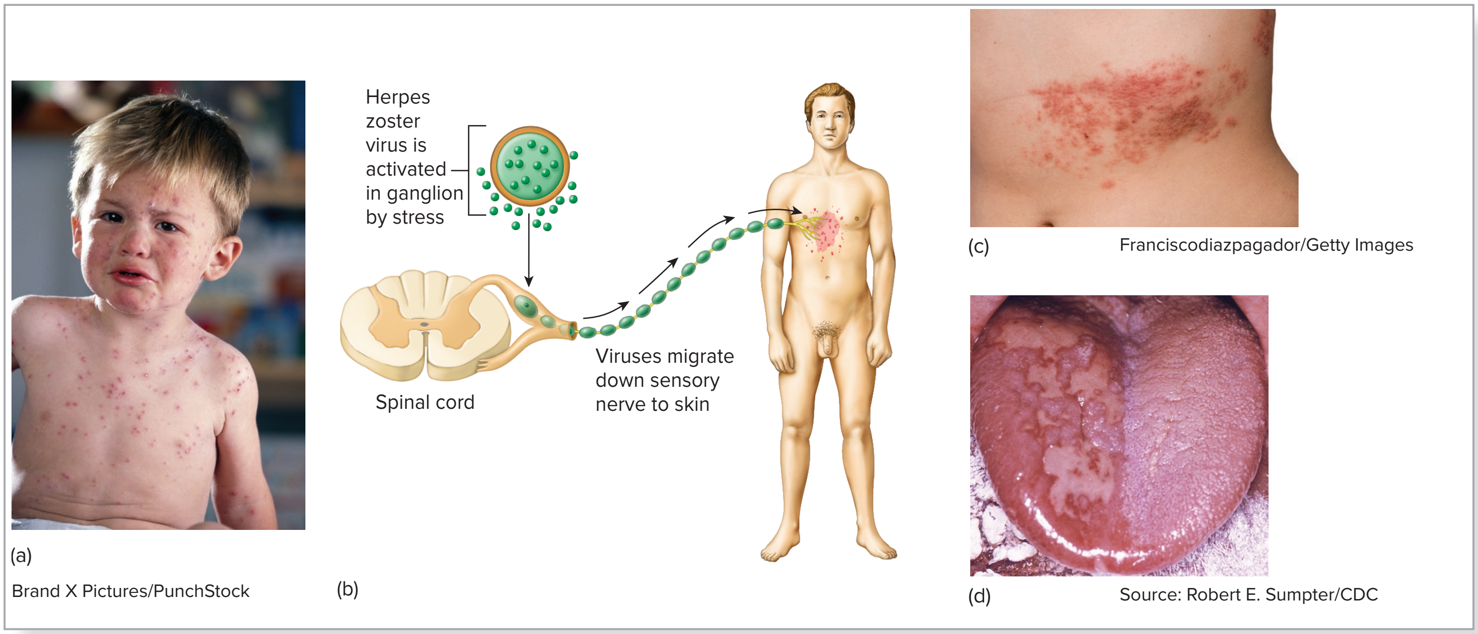



### Process Figures

Process figures break down difficult concepts to more clearly illustrate their component parts. Each step is clearly numbered, making the entire process easy to follow for all types of learners. A distinctive icon identifies each process figure and, when needed, the accompanying legend provides additional explanation.

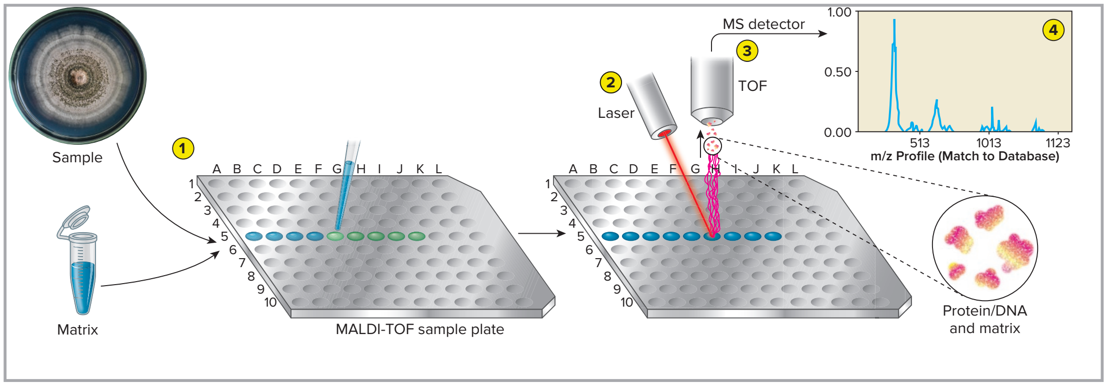


## Clinical photos help students visualize




### Modern Processes

Microbial diagnostics are not what they were 20 years ago. Automated diagnostics, rapid tests, and Point-of-Care testing are featured throughout the text.




**Process Figure 22.4 MALDI-TOF identification of a fungal sample.** **(1)** Sample of an unknown fungus is combined with a volatile matrix and applied to a metal plate. **(2)** A laser beam heats the sample and matrix, converting them to gas and ionizing DNA and protein molecules in the sample. **(3)** The ions move through a time-of-flight tube, where they are separated by size, as small ions move across the tube faster than larger ones. **(4)** The mass-to-charge ratio (m/z) for each ion is displayed as a spectrum, which is compared to the spectrum produced by other fungi (contained in a database) to determine identification.
(inset): BENPOL/Shutterstock

# Maintaining Relevance Beyond the Classroom

## Learn and Practice

Succinctly answering every student's "What do I need to know?" question, each numbered section in the book opens with learning outcomes (Learn) and closes with assessment questions (Practice). The learning outcomes are tightly correlated to digital materials and instructors can easily measure student learning in relation to the specific learning outcomes used in their course. You can also assign Practice questions to students through McGraw-Hill's Connect.

### 6.1 Overview of Viruses

**Learn**

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

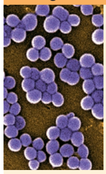
***Practice*** SECTION 13.1

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 between transient and resident microbes.
7. Explain the factors that cause variations in the microbiota of the newborn intestine and the vaginal tract.

## 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, means of identification, habitat information, and virulence factors. Artwork displays the primary infections/disease, as well as the organs and systems primarily impacted. New to the eleventh edition, each Pathogen Profile also includes a System Profile that presents the pathogen in relation to organ systems affected.

**Pathogen Profile #1** *Staphylococcus aureus*



*Source:* Janice Carr/CDC

**Microscopic Morphology** Gram-positive cocci in irregular clusters; nonmotile; non–spore-forming. May form biofilm infections on catheters and other indwelling devices.

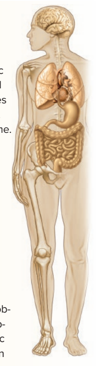
**Identified By** Growth on high-salt (7.5% NaCl or more) media, Gram reaction, and arrangement. Fermentation of sugars distinguishes *Staphylococcus* from *Micrococcus;* catalase production distinguishes *Staphylococcus* from *Streptococcus*. Coagulase production distinguishes *S. aureus* from other species of *Staphylococcus*. Commercially available rapid identification tests rely on antibody-coated latex beads that bind specifically with *S. aureus*.

**Habitat** Carried by 20% to 60% of healthy persons in the nostrils, skin, nasopharynx, and intestine. Very resistant to harsh environmental conditions and routinely present on fomites.

**Virulence Factors** *S. aureus* possesses enzymes that destroy host tissue (hyaluronidase), digest blood clots (staphylokinase), colonize oily skin (lipase), and resist the effects of penicillin (penicillinase). Toxins (leukocidins) destroy neutrophils and macrophages, lyse red blood cells (hemolysins), and cause damage throughout the body (enterotoxins, exfoliative toxins, toxic shock syndrome toxin).

**Primary Infections/Disease** Local cutaneous infections include folliculitis, furuncles, and carbuncles, as well as bullous impetigo. Systemic infections include osteomyelitis, pneumonia, and endocarditis. A rare cause of meningitis. Diseases due to *S. aureus* toxins include food intoxication, scalded skin syndrome, and toxic shock syndrome.

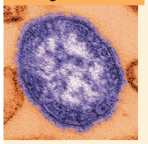
**Control and Treatment** Control of healthcare–associated infection relies on careful hygiene and adequate cleansing of surgical incisions and burns; isolation of persons with open lesions; and barring of *S. aureus* carriers from sensitive areas such as operating rooms and nurseries. Special concern is paid to the strains known as MRSA, which have high levels of drug resistance. Community-acquired infections are controlled through disinfection of shared environments and equipment. Treatment involves intensive chemotherapy, often with multiple antimicrobics. The problem of MRSA strains requires antimicrobial susceptibility testing to select a correct chemotherapeutic agent. Many cutaneous lesions require perforation and drainage prior to antimicrobic therapy.



**System Profile**

| System | Skin/Skeletal | Nervous/Muscle | Cardiovascular/ Lymphatic/Systemic | Gastrointestinal | Respiratory |
|---|---|---|---|---|---|
| Disease | 1. Boils, carbuncles<br>2. Impetigo<br>3. Scalded skin syndrome<br>4. Osteomyelitis | Meningitis | 1. Endocarditis<br>2. Toxic shock syndrome | Food intoxication | Pneumonia |

**Pathogen Profile #2** *Morbillivirus (measles virus)*



*Source:* Cynthia Goldsmith/ CDC

**Microscopic Morphology** Enveloped virus, 100 to 200 nm in diameter, containing a nonsegmented, single-stranded RNA genome.

**Identified By** Clinical presentation, especially the appearance of a maculopapular rash and Koplik's spots, which are indicative of measles. Serological testing that reveals measles-specific IgM antibodies early in the course of the disease or a rising IgG titer when comparing acute and convalescent samples confirms a diagnosis of measles.

**Habitat** Humans are the only natural reservoir for *Morbillivirus*.

**Virulence Factors** Syncytium formation.

**Primary Infections/Disease** Early symptoms of measles (rubeola) include sore throat, dry cough, headache, conjunctivitis, lymphadenitis, and fever, followed by oral lesions called Koplik's spots and a maculopapular rash over most of the body. The most serious complication is subacute sclerosing panencephalitis (SSPE), a progressive neurological disease resulting in coma and death. Less serious complications include secondary bacterial infections such as pneumonia and otitis media.

**Control and Treatment** The MMR (measles, mumps, rubella) vaccine has greatly reduced the incidence of measles, with deaths in the United States being extremely rare. Worldwide, the disease still claims about 89,000 lives each year. Treatment of measles centers on reducing fever, suppressing cough, and replacing lost fluids. In some cases, secondary bacterial infections may be treated with antibiotics, and children may receive vitamin A supplements.

**System Profile**

| System | Skin/Skeletal | Nervous/Muscle | Cardiovascular/ Lymphatic/Systemic | Gastrointestinal | Respiratory | Urogenital |
|---|---|---|---|---|---|---|
| Disease | Measles | Subacute sclerosing panencephalitis | | | | |

# Pedagogy created to promote active learning

## Clinical Connections

Clinical Connections boxes, found throughout the book, provide students with concrete examples of the central role microbiology plays in the health care environment. Generally no longer than half a page, each feature creates a link for students between microbiological theory and clinical practice. Each Clinical Connections box ends with a question requiring students to use knowledge from the chapter to analyze or evaluate real-life problems.

CLINICAL CONNECTIONS

**The Immunological Benefits of Breast-Feeding**

International symbol for breast feeding
Lukasz Stefanski/Shutterstock

An advertising slogan from the past claims that cow's milk is "nature's most nearly perfect food." One could go a step farther and assert that human milk is nature's *perfect* food for young humans. Clearly, it is loaded with essential nutrients, not to mention being available on demand from a readily portable, hygienic container that does not require refrigeration or warming. But there is another and perhaps even greater benefit. During lactation, the breast becomes a site for the proliferation of lymphocytes that produce IgA antibodies that protect the mucosal surfaces from local invasion by microbes. The very earliest secretion of the breast, a thin, yellow milk called **colostrum,** is very high in these antibodies. They form a protective coating in the gastrointestinal tract of a nursing infant that guards against infection by a number of enteric pathogens (*Escherichia coli, Salmonella,* poliovirus, rotavirus). Protection at this level is especially critical because an infant's own antibodies and natural intestinal barriers are not yet developed. As with immunity in utero, the necessary antibodies will be donated only if the mother herself has active immunity to the microbe through a prior infection or vaccination.

A critical benefit of breast-feeding that has not been given adequate credit is the connection between nursing, the breast microbiome, and the neonatal microbiome. For many years, milk was thought to be sterile unless the mother's breasts were infected. Now we know from studies on the human microbiome that breast milk and tissues harbor a diverse bacterial community that is distinct from that of the skin or the mouth. This discovery acknowledges that, in addition to its nutritional and immunological support, breast milk is an important early source of microbes that populate the newborn intestine and other body sites. A related function of the breast microbiome could be to supply bacterial stimuli for the continuing development of the baby's immune system.

For a number of years, the ready availability of artificial formulas and the changing lifestyles of women have reduced the incidence of breast-feeding. According to UNICEF, only about 38% of mothers worldwide breast-feed their babies for 6 months or more. Where adequate hygiene and medical care prevail, bottle-fed infants get through the critical period with few problems because the foods given them are relatively free of pathogens and they have received protection against some childhood infections in utero. Mothers in developing countries with untreated water supplies or poor medical services are strongly discouraged from using prepared formulas, because they can actually inoculate the baby's intestine with pathogens from the formula. Millions of neonates suffer from severe and life-threatening diarrhea that could have been prevented by sustained breast-feeding. The use of formula has been so damaging to infant health that the World Health Organization issued an *International Code on the Marketing of Breast Milk Substitutes,* discouraging the use of formula in the developing world.

**Explain the reasons donated antibodies (either placental or in breast milk) are only a temporary protection.**

## Quick Search

This feature reminds students that videos, animations, and pictorial displays that provide further information on the topic are just a click away using their smartphone, tablet, or computer. This integration of learning via technology helps students become more engaged and empowered in their study of the featured topic.

**Quick Search**

Search the Web using the phrase "Bacterial Pathogen Pronunciation Station" for help in correctly pronouncing some common scientific names.

**Quick Search**

To compare the types of movement seen in eukaryotes, find videos using the search words *amoebic, flagellate,* and *ciliate movement* on YouTube.

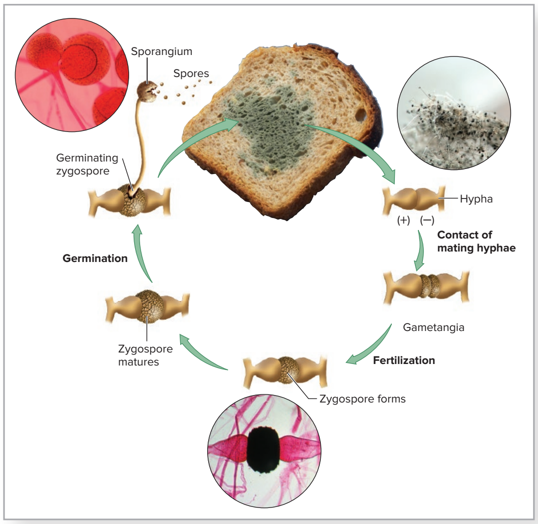
## Footnotes

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

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

## Combination Figures

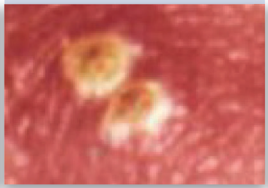
Line drawings combined with photos give students two perspectives: the realism of photos and the explanatory clarity of illustrations. The authors chose this method of presentation often to help students comprehend difficult concepts.




(mold on bread): Richard Hutchings/McGraw-Hill Education; (mold): Mitroshkin/Getty Images; (Rhizopus sporangia and zygote): Richard Gross/McGraw-Hill Education

## Illustrated Tables

Illustrated tables provide quick access to information. Horizontal contrasting lines set off each entry, making them easy to read.

| **Category** | **Mycobacteria** | **Gram-Negative Bacteria** | **Gram-Positive Bacteria** | **Chlamydias** | **Rickettsias** |
|---|---|---|---|---|---|
| Disease | Hansen's Disease (Leprosy) | Plague | *Staphylococcus* infections | Trachoma | Rocky Mountain spotted fever |
| |  |  |  |  |  |
| Other examples | Tuberculosis | Salmonellosis, gonorrhea | Strep throat | Chlamydia | Typhus |
| Spectrum of antibiotic activity* | Isoniazid<br>Streptomycin<br>Tobramycin<br>Polymyxin<br>Carbapenems<br>Tetracyclines<br>Sulfonamides<br>Cephalosporins<br>Penicillins | | | | |

*Resistant strains of bacteria may occasionally be encountered, meaning that an antibiotic may not always be effective, even for bacteria that seem to fall within its spectrum of action.

(Tuberculosis): NikomMaelao Production/Shutterstock; (Salmonellosis): *Source:* CDC; (Strep throat): McGraw-Hill Education *Source:* Susan Lindsley/CDC; (Chlamydia): Susan Lindsley is the source for Chlamydia (Typhus): *Source:* CDC

# Clinic Cases

New to this edition, *Clinic Cases* are short case studies that typically focus on a single aspect of a chapter. They provide relevance for lessons learned and easily serve as collaborative warm-up activities.

### CLINIC CASE

**If Only We Could Give You a Mutation** The patient, Timothy Ray Brown, presented to doctors in Berlin with overwhelming fatigue. Used to 20 miles a day on his bicycle back and forth to work, he was suddenly unable to make the one-mile ride to a restaurant near his office. Diagnosed with the human immunodeficiency virus (HIV) 10 years earlier, Brown had been keeping the virus in check with a combination of AZT and protease inhibitors. He was in good health and had a life expectancy about the same as someone uninfected by the virus. Doctors in Berlin diagnosed Brown with anemia (unrelated to his HIV) and provided blood transfusions to increase the number of circulating erythrocytes. An oncologist performed a bone marrow biopsy, and less than a week after his initial symptoms, Brown was diagnosed with acute myeloid leukemia (AML), a cancer of the bone marrow.

After several failed rounds of chemotherapy, doctors brought up the idea of a bone marrow transplant, a treatment for leukemia in which the bone marrow, both cancerous and healthy, is destroyed and new, healthy bone marrow is transplanted into the body. Brown's doctor wanted to go one step further though, and proposed a treatment that would, perhaps, cure Brown of his HIV at the same time.

To enter cells of the immune system, the human immunodeficiency virus must first bind to a cell surface receptor protein known as CCR-5. Approximately 1% of the population has a mutation in both copies of their CCR-5 gene (called CCR-5 delta 32, or CCR-5 Δ32) that creates a stop codon. HIV cannot use these mutant proteins to enter the cell and is therefore unable to replicate. If a bone marrow donor with the CCR-5 Δ32 mutation could be found, perhaps Brown's AML and HIV could be cured simultaneously.

As luck would have it, Brown is of northern European descent and the CCR-5 Δ32 mutation is most commonly found in that group as well. An appropriate donor was found that possessed the mutation and Brown underwent transplant on February 6, 2007, the same day he stopped taking his anti-HIV medication. A second transplant, from the same donor, was required in 2008, but in more than 10 years, Brown has shown no signs of his HIV progressing, leaving him the first person cured of HIV infection.

**Δ32 refers to a 32-base-pair deletion in the CCR-5 gene. Besides a deletion mutation and nonsense mutation, what other type of mutation was created in the gene?**

### CLINIC CASE

**Plague Is Not an Opportunistic Infection, Unless...** The patient was Malcolm Casadaban, a 60-year-old professor at the University of Chicago who was well known for his work with *Yersinia pestis*, the bacterium that causes bubonic plague. A primary pathogen responsible for the death of more than 100 million people in the 1300s, outbreaks of plague were still seen from time to time, and Casadaban was working to develop a vaccine to protect against the disease. But even plague researchers get the flu from time to time, and this is what compelled Dr. Casadaban to visit his primary care physician.

Not surprisingly, given his occupation, the first question the doctor asked was, "Do you work with *Yersinia pestis*?" Casadaban assured his doctor that he worked exclusively with an attenuated strain of the bacterium that required excess iron—more than was normally found in the human body—to reproduce. While it grew well in the lab, there was no chance this strain could cause disease. Assured that he wasn't dealing with the "Black Death," the doctor diagnosed a viral infection and sent Dr. Casadaban home with instructions to rest. Three days later, he returned to the hospital, very sick, and soon thereafter died.

An autopsy revealed the supposedly innocuous strain of *Yersinia pestis* in his system, but the researcher's demise remained a mystery. How could such a weakened strain of *Yersinia pestis* cause death? Analysis of the doctor's blood finally solved the puzzle. Unbeknownst to him, Dr. Casadaban suffered from hemochromatosis, a genetic disorder in which people accumulate high levels of iron in their blood. This excess of iron allowed the usually iron-starved *Yersinia pestis* to assume its original virulence. Dr. Casadaban's condition increased his susceptibility to a single bacterial species, the one he had been working with for years.

**Drugs meant to reduce stomach acid (to combat heartburn) may make the patient more susceptible to infection by bacteria that pass through the gastrointestinal tract. How is this situation similar to what happened to Dr. Casdaban?**

# Organized to Promote Critical Thinking

## Pedagogy designed for varied learning styles

The end-of-chapter material for the eleventh edition has been carefully planned and updated to promote active learning and provide review for different learning styles and levels of Bloom's Taxonomy.

### 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**

**3.1 Methods of Microbial Investigation**

A. Microbiology as a science is very dependent on a number of specialized laboratory techniques.
1. Initially, a specimen must be collected from a source, whether environmental or patient.
2. **Inoculation** of a **medium** with the specimen is the first step in **culturing.**
3. **Incubation** of the medium with the microbes under the right conditions creates a **culture** with visible growth.
4. **Isolation** of the microbes in the sample into discrete, separate **colonies** is one desired goal.
5. **Inspection** begins with macroscopic characteristics of the culture and continues with microscopic analysis.
6. **Information gathering** involves acquiring additional data from physiological, serological, and genetic tests.
7. **Identification** correlates the key characteristics that can pinpoint the actual species of microbe.

### End-of-Chapter Questions

Questions are divided into two levels.

**Assess Your Knowledge**

**Level I.** These questions require a working knowledge of the concepts in the chapter and the ability to recall and understand the information you have studied.

**Application, Analysis, Evaluation, and Synthesis**

**Level II.** 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.

### Case Study Analysis

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 Analysis**

1. Small intestinal bacterial overgrowth (known by its acronym, SIBO) is a condition similar to gut fermentation syndrome. SIBO occurs when an overabundance of bacteria, rather than yeast, in the small intestine ferment carbohydrates. What product would be produced in the gut of someone suffering from SIBO?

### On the Test

On the Test questions cover material from the chapter that may appear on the TEAS (Test of Essential Academic Skills) or NCLEX (National Council Licensure Exam). Written in the style seen on each exam, these questions help students forge a link between the chapter contents and two of the most important exams they'll take in the future.

**On the Test**

These questions will help to prepare you to successfully answer similar questi NCLEX (National Council Licensure Examination).

1. The nurse gives a primigravida (first pregnancy) client an injection of RhoGAM during the 28th week of her pregnancy. Why was the nurse required to take this action?
   a. The mother was Rh-negative while the father was Rh-positive.
   b. The mother was Rh-positive while the father was Rh-negative.
   c. The mother was O-negative while the father was Ab-positive.
   d. Both the mother and father were Rh-positive.

### 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 that includes the f questions can also be used for writing-challenge exercises.

1. Discuss the relationship of
   a. anabolism to catabolism
   b. ATP to ADP
   c. glycolysis to fermentation
   d. electron transport to oxidative phosphorylation

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!

### Developing a Concept Inventory

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.

**Developing a Concept Inventory**

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

1. An example/examples of a nonspecific chemical barrier to infection is/are
   a. unbroken skin　　c. cilia in respiratory tract
   b. lysozyme in saliva　　d. all of these
2. Which nonspecific host defense is associated with the trachea?
   a. lacrimation　　c. desquamation

# Organized to Promote Critical Thinking

## Concept Mapping

Concept Mapping activities have been designed for each chapter, and 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. a. What is the main clinical strategy in preventing gas gangrene?
   b. Why does it work?
2. a. Why is it unlikely that diseases such as tetanus and botulism will ever be completely eradicated?
   b. Name some bacterial diseases in this chapter that could be completely eradicated and explain how.
3. Why is the cause of death similar in tetanus and botulism?
4. a. Why does botulinum toxin not affect the senses?
   b. Why does botulism not commonly cause intestinal symptoms?
5. Account for the fact that boiling does not destroy botulism spores but

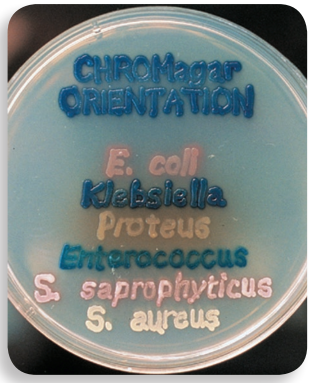
8. What would be the likely consequence of diphtheria infection alone without toxemia?
9. How can one tell that acne involves an infection?
10. Do you think the spittoons of the last century were effective in controlling tuberculosis? Why or why not?
11. a. Provide an explanation for the statement that TB is a “family disease.”
    b. What, if anything, can be done about multidrug-resistant tuberculosis?
    c. Explain an important rationale for *not* administering BCG vaccine in the United States to the general public.

## Visual Assessment

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

**Visual Assessment**

1. From **chapter 3, figure 3.18*b*.** Which bacteria have a well-developed capsule: *“Klebsiella”* or *“S. aureus”*? Defend your answer.




Kathy Park Talaro

# Changes to *Foundations in Microbiology, Eleventh Edition*

## Global Changes to the Eleventh Edition

- Chapter-opening pages include a content outline, helping to emphasize the chapter organization.
- Clinic Cases appear in every chapter to highlight important topics.
- End-of-chapter questions in the style of the TEAS and NCLEX exams have been added.

## Chapter-Specific Changes

### Chapter 1

- New introduction to viruses and prions
- Clinic Case concerning *Microcystis* poisoning
- Discussion concerning the changing nature of infectious disease and microbial roles in noninfectious disease
- Ten new photographs

### Chapter 2

- New Case Study on lactose intolerance
- Clinic Case illustrating the pH-dependent germination of *Clostridium botulinum*
- Six new photos and illustrations

### Chapter 3

- New Case Study concerning the laboratory diagnosis of *Salmonella* Typhi
- Clarified discussion of fluorescence microscopy
- Clinic Case concerning anthrax infection in New York City
- Discussion of unculturable microorganisms
- Nineteen new photographs and illustrations

### Chapter 4

- New Case Study concerning biofilm formation within dental equipment
- Process figure on biofilm formation
- Discussion of capsules, biofilms, and quorum sensing
- Clinic Case concerning gas gangrene in an IV drug user
- Twelve new photographs and illustrations

### Chapter 5

- New Case Study concerning *Amanita phalloides* (death cap mushroom) poisoning
- Discussion of the eukaryotic cytoskeleton has been clarified
- Eukaryotic classification has been updated to reflect the latest findings
- Clinic Case concerning paralytic shellfish poisoning
- Clinic Case involving roundworm infection of a toddler
- Twenty-seven new photographs and illustrations

### Chapter 6

- New Case Study dealing with bacteriophage therapy
- Clinic Case examining a monkeypox infection in Wisconsin
- Discussion of persistent viral infections
- Clinic Case concerning an incident of variant Creutzfeldt-Jakob disease
- Nine new photographs and illustrations

### Chapter 7

- New Case Study concerning *Vibrio vulnificus* infection related to a recent tattoo
- Clinic Case concerning *Vibrio parahaemolyticus* infections related to warming oceans
- Modified discussion concerning associations between microbes
- Eleven new photographs and illustrations

### Chapter 8

- New Case Study on auto-brewery syndrome
- Clinic Case on the use of ethanol as an antidote to methanol poisoning
- Clarified discussion of electron carriers
- Discussion of glycolysis has been clarified, and reactions are divided into "first five" and "second five"
- Four new photographs and illustrations

### Chapter 9

- New Case Study concerning the 14th known case of vancomycin-resistant *Staphylococcus aureus*
- Clarified discussion of DNA structure and replication, transcription and translation, and mutations
- Clinic Case on the use of a bone marrow donor carrying a CCR-5 mutation being used to cure the recipient's HIV
- Six new photographs and illustrations

### Chapter 10

- New Case Study on the use of genetically engineered mosquitoes to reduce Zika virus infection
- Discussion of genetic engineering, restriction enzymes, and electrophoresis
- Discussion of transcriptomics, proteomics, metagenomics, and metabolomics
- Updated discussion on the potential benefits of GMOs
- Clinic Case discussing the use of modified bacteria as a treatment for phenylketonuria
- Discussion of the CRISPR/Cas-9 system for editing DNA
- Discussion of gene therapy used to correct blindness due to Leber congenital amaurosis
- Clinic Case concerning the use of familial DNA fingerprinting to identify the Grim Sleeper serial killer
- Nine new photographs and illustrations

### Chapter 11

- New Case Study concerning infection linked to improper disinfection of duodenoscopes at UCLA
- Clarified discussion of sterilization with regard to prions
- Clinic Case concerning a case of botulism due to inadequate processing of commercially canned chili
- Clinic Case concerning the use of ultraviolet light to disinfect the water in an interactive fountain
- Seven new photographs and illustrations

### Chapter 12

- New Case Study illustrating the side effects of fluoroquinolone antibiotics
- Terminology has been added, updated, and clarified throughout the chapter
- New drugs used to cure hepatitis C and prevent replication of influenza are discussed
- Expanded discussion of new HIV drugs used to fight existing infection or as pre-exposure prophylactics
- The relationship between biofilms and drug resistance is now part of the chapter
- A feature on clinical testing of antimicrobics is included in the chapter
- A Clinic Case concerning the use of intentional drug interaction to treat a drug overdose has been added
- Nineteen new photographs and illustrations

### Chapter 13

- The role of viruses as normal microbiota is addressed
- Clinic Case concerning a plague researcher who dies from infection with an attenuated strain of *Yersinia pestis*
- Clinic Case concerning an MRSA outbreak in a newborn nursery
- Disease statistics have been updated throughout the chapter
- The discussion of epicurves has been clarified
- Twenty-one new photographs and illustrations

### Chapter 14

- New Case Study concerning autosplenectomy related to lupus
- Clarified discussion of the body's interconnections with regard to the immune system
- Clinic Case exploring an occurrence of trichinellosis resistant to freezing

- Clarified discussion of hematopoiesis and the role of natural killer cells
- Nine new photographs and illustrations

## Chapter 15

- New Case Study regarding an incident of necrotizing fasciitis
- Figures used to clarify the genetics of antibody generation, and the activation of T cells
- Expanded discussion of T helper 17 cells, T regulatory cells, Gamma-Delta T cells, natural killer cells, and natural killer T cells
- New figure explaining the outcomes of antibody binding of antigen
- Updated discussion on the use of monoclonal antibodies
- Clinic Case following an outbreak of measles in Minnesota
- Clarified discussion of hematopoiesis and the role of natural killer cells
- Fifteen new photographs and illustrations

## Chapter 16

- New Case Study following a case of anti-NMDAR encephalitis, an autoimmune disease resulting in severe neurologic changes
- Updated information concerning the development of food allergies and treatments for severe allergic reactions
- Clinic Case following four cases of transplant-transmitted infection
- Seven new photographs and illustrations

## Chapter 17

- New Case Study following a case of meningitis due to lymphocytic choriomenigitis virus
- New discussions of fluorescent in-situ hybridization, pulsed-field gel electrophoresis, and whole genome sequencing
- Clinic Case concerning misidentification of a bacterial isolate as a potential bioterrorism agent
- Clarified discussion of ELISA
- Eight new photographs and illustrations

# Acknowledgments

The biggest lies are told before the marriage, after the hunt, and during the election.

***—Otto von Bismarck***

And the biggest lie of all may be "I write a book." Because writing a book is most definitely a team sport. And thank-you's are owed to the rest of the team.

Beginning of course with microbiology itself, a subject whose ever-changing nature means that after just a few years, a book begins to look antiquated, irrelevant, even silly. A few editions ago, there was little thought given to Zika virus, probiotics, or the microbiome, topics of great import today. So the first thanks go to the science itself and those who spend their days (and nights, and weekends) coaxing answers from the smallest of organisms.

To the students, instructors, and colleagues who've used the book, sent an email, suggested a change, or simply walked up with book in hand and a quizzical expression which said "Huh?," thank you. Your suggestions have never once fallen upon deaf ears, and you've helped me to hopefully make this edition better than the last. A special shout-out to to Anna Oller of the University of Central Missouri and Elizabeth Co of Boston University, who reviewed the chapters on host defenses.

More thanks to the people who really know how to write a book and can cogently discuss typefaces, obtain permissions, and corral writers: the editorial and production staff at McGraw-Hill Education. For the eleventh edition, I have been fortunate to work with product developer Krystal Faust (anyone tasked to develop me deserves thanks) and brand manager Lauren Vondra (anyone tasked to manage me…). Marketing manager Jim Connely, project manager Ann Courtney, content licensing specialist Lorraine Buzcek, designer Jessica Cuevas, copyeditor Nicole Schlutt, and, in what is only a slight exaggeration, a cast of thousands. When I say I couldn't have done it without them, realize that in the absence of these people, you'd be, at best, holding my coffee-stained notes in your hands.

Despite the careful work of all these people, typos, errors, and oversights may make it to the printed page. These errors belong solely to me. If you find an error or wish to make other comments, feel free to contact the publisher, sales representative, or myself (barry.chess.micro@gmail.com). Enjoy.

***—Barry Chess***

# To the Student

When you awoke this morning, the coating you felt on your teeth was a bacterial biofilm. For every human cell of your body, at least three cells are not human. Remember the time you didn't get smallpox, polio, and measles. How about that safe water? Enjoy yogurt? Cheese? Bread? Beer? Have I made my point?

Microbiology is often the very essence of "Out of sight, out of mind," but it is my sincere hope that this book can change that. For most of you, this course is a required prerequisite for your chosen career, but microbiology is so much more than that. From before we're born until after we die, we have an intimate association with all manner of microorganisms, and the goal of this book is to make these relationships more familiar. Which organisms are dangerous? Beneficial? Useful? Along the way, there will be Greek terminology, a little chemistry, and some math. Sorry.

As you use this book, please *use* this book, it was designed solely with you in mind. Study the photographs, look up unfamiliar words, answer the questions, make the information yours. Without even being aware of it, you'll gain a greater understanding of not only the world around you, but the world within you. Not a bad way to spend some time.

***—Barry Chess***

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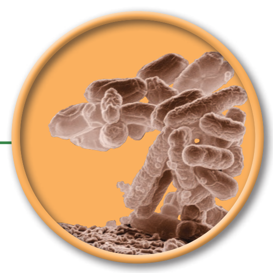

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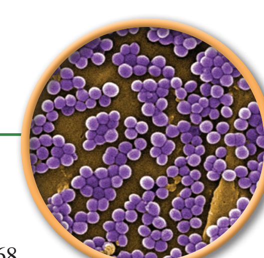

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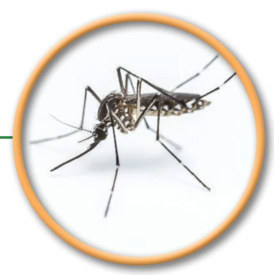

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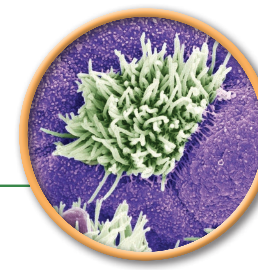
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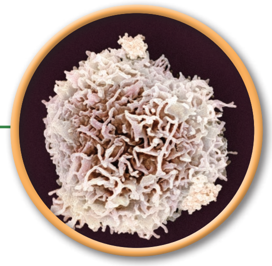
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CHAPTER **17**

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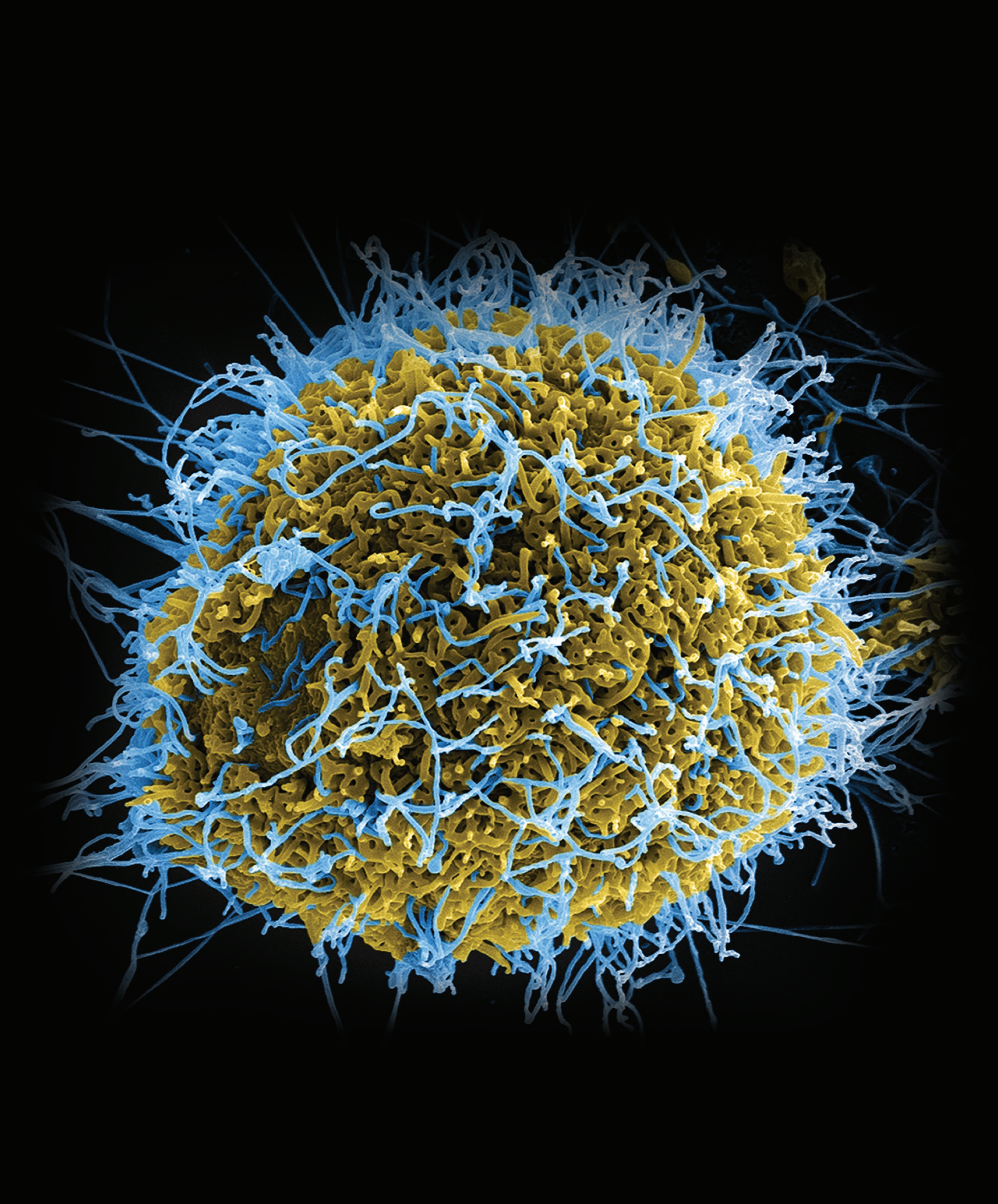
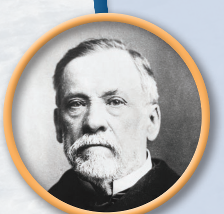
Kristopher Grunert/Corbis



CHAPTER

1

# The Main Themes of Microbiology



## In This Chapter...



*(Water sample from Lake Whillans): JT Thomas; (White wine): John Thoeming/McGraw-Hill Education; (Mycobacterium): Source: Janice Carr/CDC; (algae): Source: Christopher Botnick/NOAA; (mosquito): Source: Frank Hadley Collins, Dir. Center for Global Health and Infectious Diseases; University of ND/CDC; (Louis Pasteur): Pixtal/age fotostock*

## CASE STUDY Part 1 Microbes Find a Way

A frozen white wasteland, a toxic soup. Two 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.

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.*

*(methane bubbles arise from the sea floor) Source: NOAA Okeanos Explorer Program, 2013 ROV Shakedown and Field Trials in the U.S. Atlantic Canyons.*

## 1.1 The Scope of Microbiology

Learn

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 microscopic universe is populated by a vast microbial menagerie that is equally beautiful and complex. To sum up the presence of microbes in one word, they are **ubiquitous.*** They are found in all natural habitats and most of those that have been created by humans. As scientists continue to explore remote and unusual environments, the one 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 each other and the environment, and their uses in industry and agriculture.

In fact, many areas of the field have become so specialized that a microbiologist may spend an entire career focused on a single subspecialty, a few of which are:

- Bacteriology—the study of bacteria; small, single-celled prokaryotic organisms
- Mycology—the study of fungi; eukaryotic organisms that include both microscopic (molds and yeasts) and larger members like mushrooms, puffballs, and truffles
- Protozoology—the study of protozoa; a group of mostly single-celled eukaryotes
- Virology—the study of viruses; noncellular particles that parasitize cells
- Parasitology—the study of parasites; traditionally including pathogenic protozoa, helminth worms, and certain insects
- Phycology or algology—the study of simple photosynthetic eukaryotes, the algae; ranging from single-celled forms to large seaweeds
- Morphology—the study of the detailed structure of microorganisms
- Physiology—investigation of organismal metabolism at the cellular and molecular levels
- Taxonomy—the classification, naming, and identification of microorganisms
- Microbial genetics and molecular biology—the study of the genetic material and biochemical reactions that make up a cell's metabolism
- Microbial ecology—the interrelationships between microbes and the environment; the roles of microorganisms in nutrient cycles and natural ecosystems

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, systems of inheritance, and the global cycles of nutrients, minerals, and gases. **Table 1.1** describes just a few of the occupations included within the greater field of microbiology.

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

Learn

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.

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### The Origins and Dominance of Microorganisms

For billions of years, microbes have 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

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

## TABLE 1.1 A Sampling of Fields and Occupations in Microbiology

### Medical Microbiology, Public Health Microbiology, and Epidemiology

Medical microbiology, which studies the effects of microorganisms on human beings, remains the most well-known branch of microbiology. The related fields of public health and epidemiology 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 *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:* Scott Bauer/USDA

### 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

### Biotechnology, Genetic Engineering, and Industrial Microbiology

These branches revolve around the idea that microorganisms can be used to derive a desired product, from beer to vaccines. Biotechnology focuses on the natural abilities of microbes, while genetic engineering involves the deliberate alteration of the genetic makeup of organisms to create novel microbes, plants and animals with unique behaviors and physiology. Industrial microbiology is the science of scaling up these processes to produce large quantities of a desired product (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

### 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:* Black Star/Steve Yeater for FDA

### 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:* Keith Weller/USDA

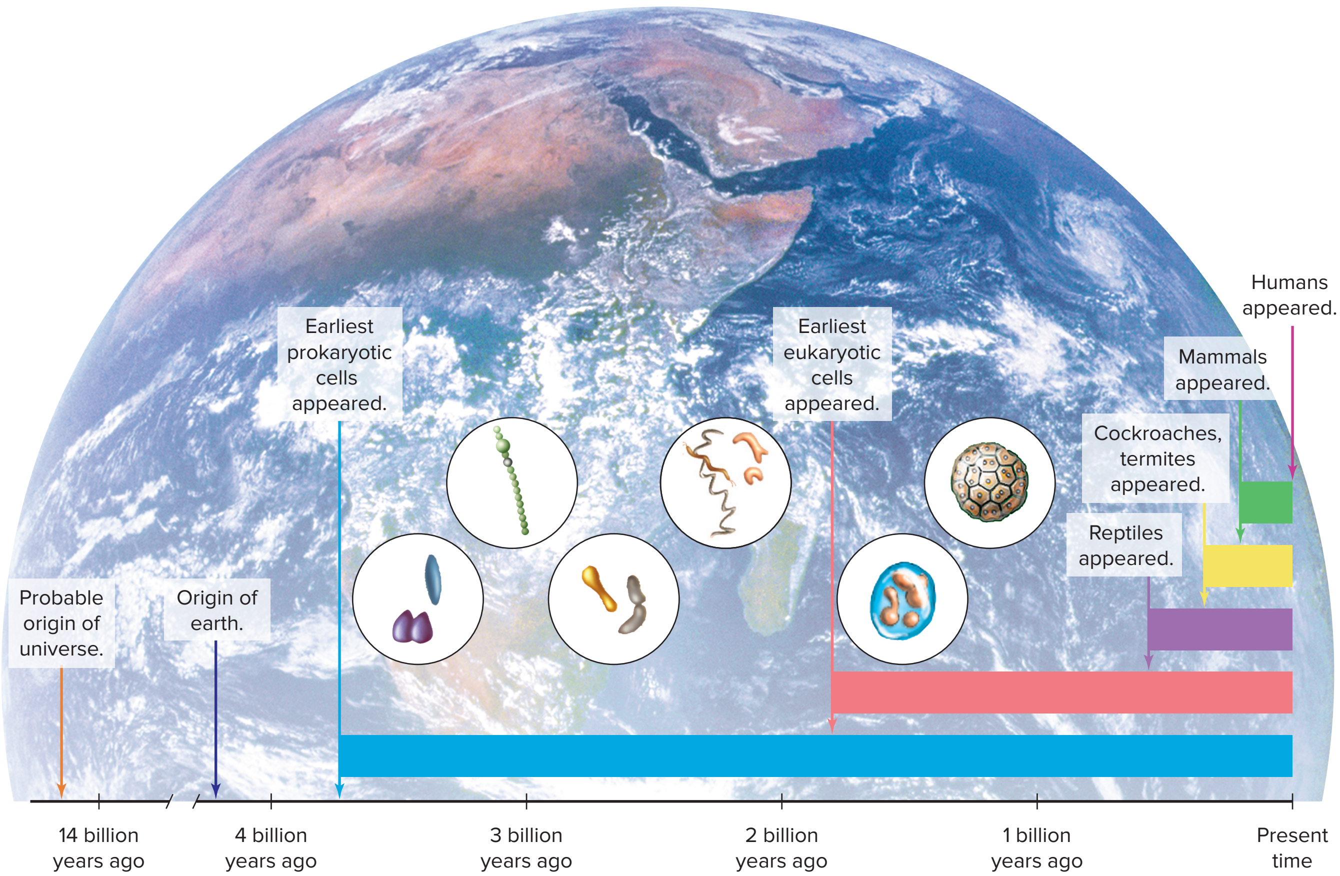



**Figure 1.1 Evolutionary time line.** The first simple prokaryotes appeared on earth approximately 3.5 billion years ago, and the first eukaryotes arose about 2 billion years ago. Although these appearances seem abrupt, hundreds of millions of years of earth's history passed while they were evolving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

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. The 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.

## 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, and they include the bacteria and archaea. 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 micro-

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

(a) **Basic cell types** (b) **Examples of viruses**

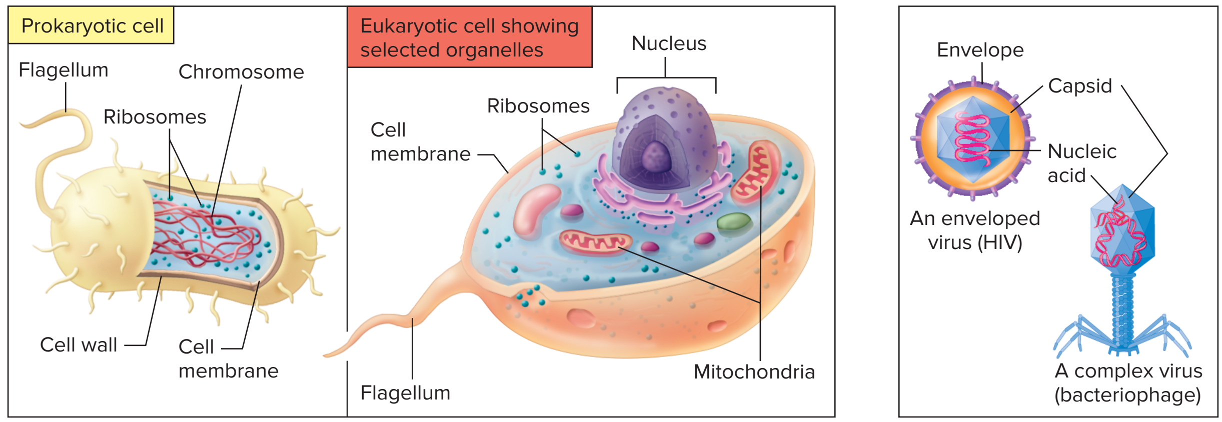
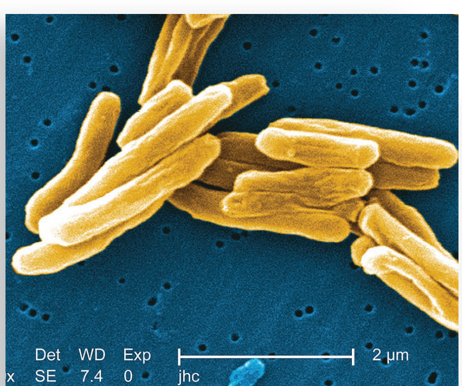
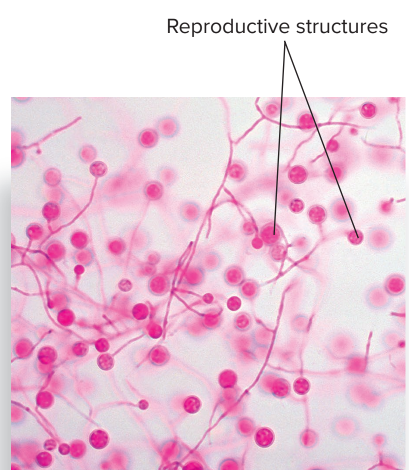


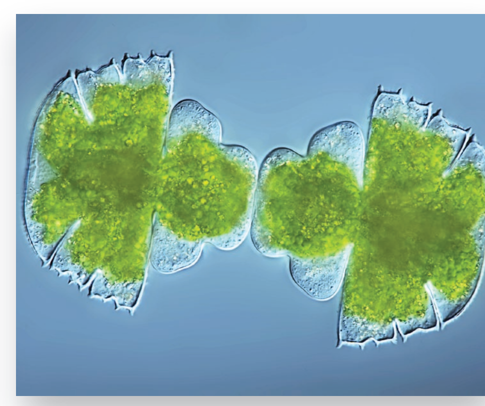

**Figure 1.2 Basic structure of cells and viruses.** **(a)** Comparison of a prokaryotic cell and a eukaryotic cell. **(b)** Two examples of viruses. These cell types and viruses are discussed in more detail in chapters 4, 5, and 6.



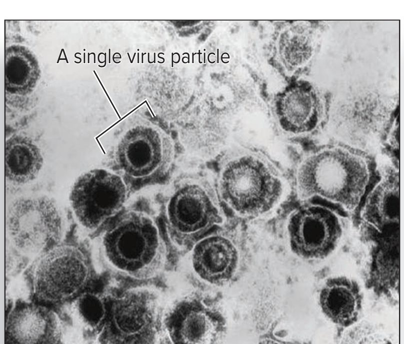

Bacteria: *Mycobacterium tuberculosis,* a rod-shaped cell (15,500×).



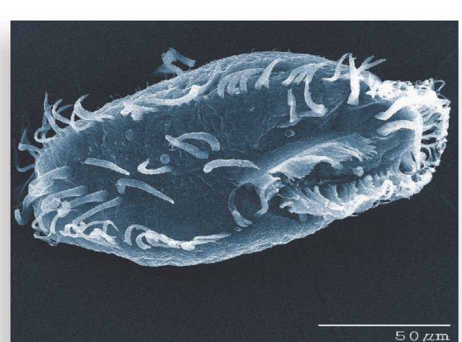

Fungi: *Histoplasma capsulatum*, with lollipop-like reproductive structures (750×). This agent is the cause of Ohio Valley fever.



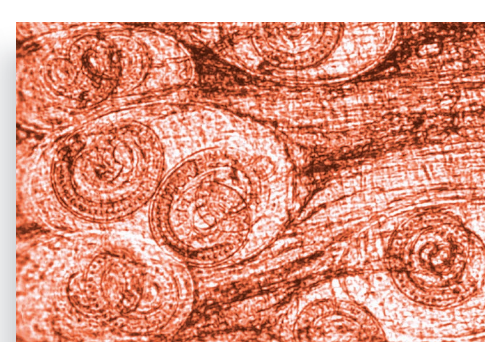
Algae: *Micrasterias truncata* (750×), one of the predecessors of modern-day plants.




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




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



Helminths: Roundworms of *Trichinella spiralis* coiled in the muscle of a host (250×). 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): Lebendkulturen.de/Shutterstock; (virus): *Source:* Dr. Erskine Palmer/CDC; (protozoa): *Source:* National Human Genome Research Institute; (helminths): *Source:* CDC scopic, 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.

## Noncellular Pathogenic Particles—Viruses and Prions

Viruses are well-studied in microbiology, as they are the most common microbes on earth and are responsible for diseases ranging from the common cold to AIDS, but they are not cells. Rather, viruses are small particles composed of a small amount of hereditary material, surrounded by a protein coat, and are so simple that most biologists don't consider them to be alive (primarily because they are incapable of replication on their own).

Prions—a contraction of the words *proteinaceous infectious particle*—are even simpler than viruses, consisting solely of protein. The very existence of prions was doubted until the late twentieth century, but they are now recognized as the causative agent of transmissible spongiform encephalopathies, a group of invariably fatal diseases, including mad cow disease and its human counterpart Creutzfeld-Jakob disease. Both viruses and prions will be examined in greater depth in chapter 6.

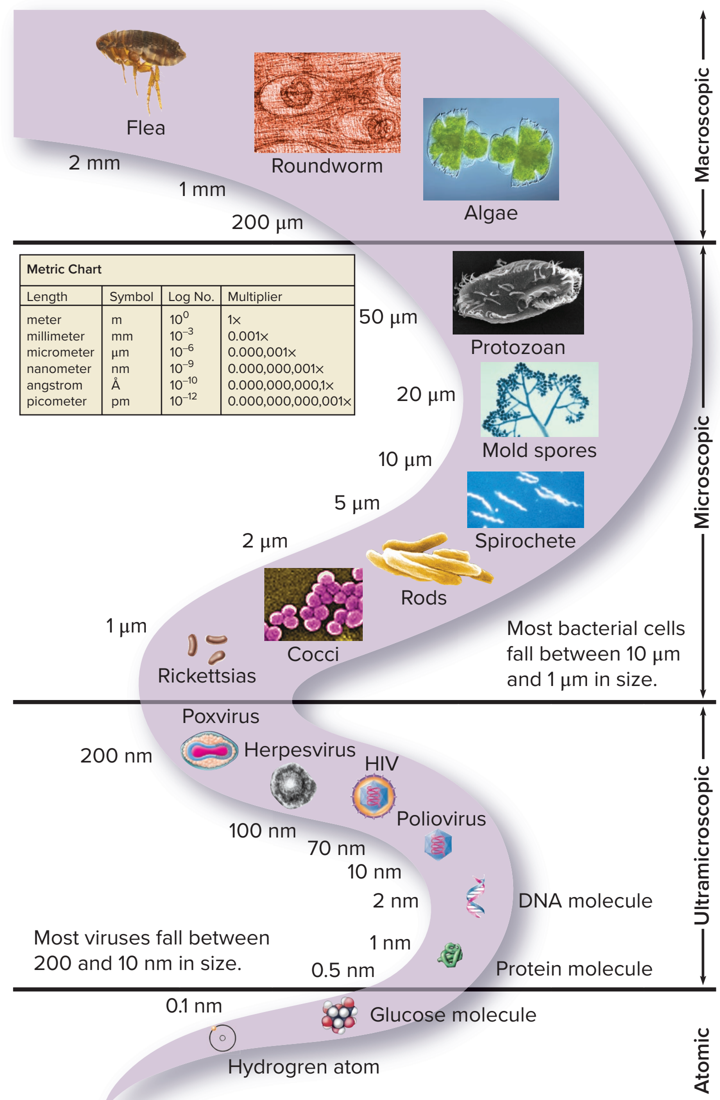
## Microbial Dimensions: How Small Is Small?

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 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*).**




Metric Chart

| Length | Symbol | Log No. | Multiplier |
|---|---|---|---|
| meter | m | $10^{0}$ | 1× |
| millimeter | mm | $10^{-3}$ | 0.001× |
| micrometer | µm | $10^{-6}$ | 0.000,001× |
| nanometer | nm | $10^{-9}$ | 0.000,000,001× |
| angstrom | Å | $10^{-10}$ | 0.000,000,000,1× |
| picometer | pm | $10^{-12}$ | 0.000,000,000,001× |

**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.

(flea): Cosmin Manci/Shutterstock; (roundworm): *Source:* CDC; (algae): Lebendkulturen.de/Shutterstock; (protozoan): *Source:* National Human Genome Research Institute; (mold spores): Dr. Lucille K. Georg/CDC; (spirochete): *Source:* CDC; (rods, cocci): *Source:* Janice Carr/CDC; (herpesvirus): *Source:* Jeff Hageman, M.H.S./Janice Carr/CDC

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

## CLINIC CASE

**Toxic Treatments** Like over 100,000 of his Brazilian countrymen (and over half a million people in the United States), Arnaldo Luis Gomes suffered from kidney failure and depended on dialysis to keep him alive. Three days a week he visited a clinic in the city of Caruaru and spent 4 hours tethered to a machine that cleansed the toxins from his blood. On this day, however, he knew something was wrong. His head hurt, his stomach ached, and the whites of his eyes began to turn yellow with jaundice, a sure sign that his liver was failing. Despite the best efforts of his doctors, 2 hours later he was dead from toxic hepatitis. Over the next 3 days, more than 100 patients had similar symptoms.

The culprit was identified as *Microcystis*, a type of algae which produces a powerful liver toxin. Unlike most bacterial contamination, water containing high levels of *Microcystis* cannot be made safe by boiling; only removal of the algae can guarantee safety. An investigation revealed that inadequate filtration of water from a local reservoir allowed the use of toxin-laden water in the clinic, eventually killing 46 clients.

Brazil is not the only place where toxic algae is a health concern. Toledo, Ohio—which gets its drinking water from Lake Erie—typically has several days each summer when tap water is unsafe to drink due to high levels of *Microcystis*. A combination of abundant sunlight from long summer days and agricultural runoff into Lake Erie promote the growth of algae to dangerous levels in the lake, which is exactly what happened in Brazil.

**Speculate on why algae blooms, like the ones in Lake Erie, typically occur in summer.**

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, microorganisms are greatly responsible for 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.

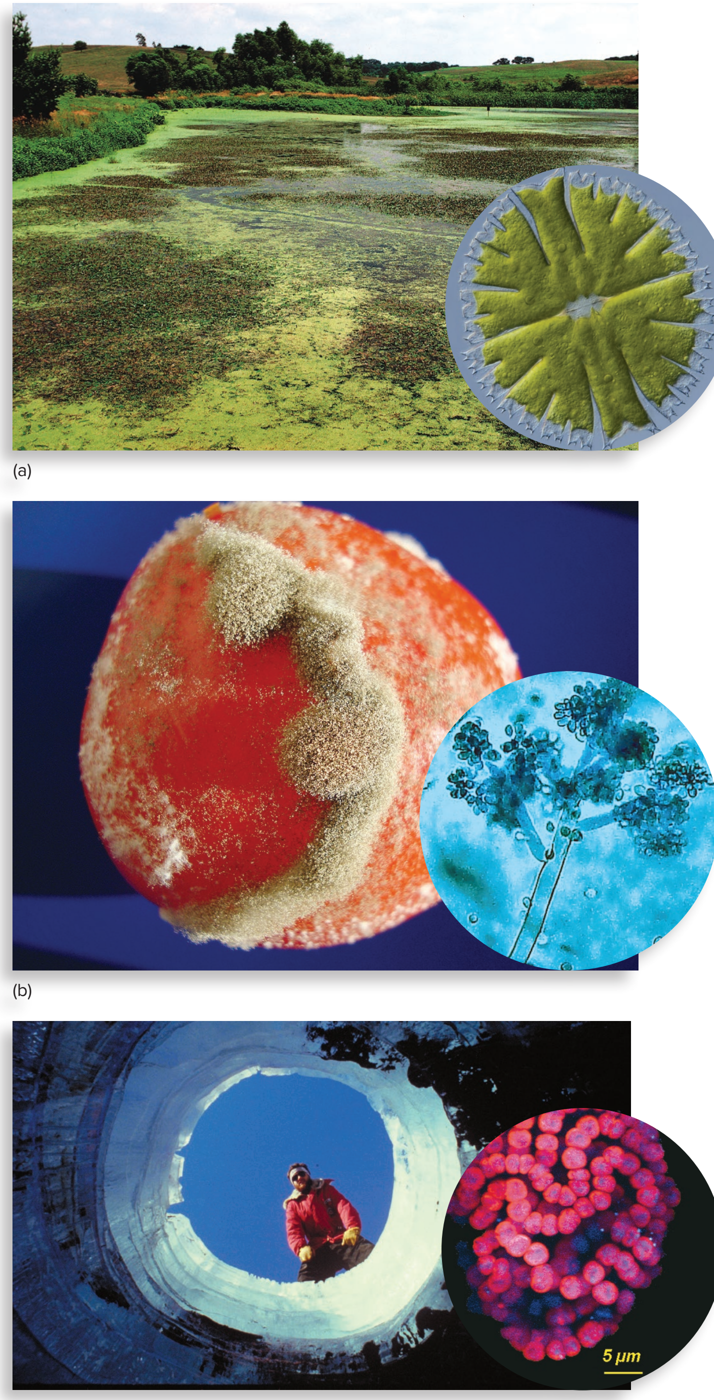



**Figure 1.5 A microscopic wonderland. (a)** A summer pond is heavily laden with surface scum that reveals several different types of green algae called desmids (*Micrasterias rotata,* 600×). **(b)** A rotting tomato being invaded by a fuzzy forest of mold. The fungus is *Botrytis,* a common decomposer of tomatoes and grapes (250×). **(c)** Tunneling through an ice sheet in Antarctica, one of the coldest places on earth (–35°C), to access hidden microbes. 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:* Lynn Betts, USDA Natural Resources Conservation Service; (a, inset): Lebendkulturen.de/Shutterstock; (b & b, inset): Kathy Park Talaro; (c): *Source:* Ames Research Center/NASA; (c, inset): Image courtesy of the Priscu Research Group, Montana State University, Bozeman