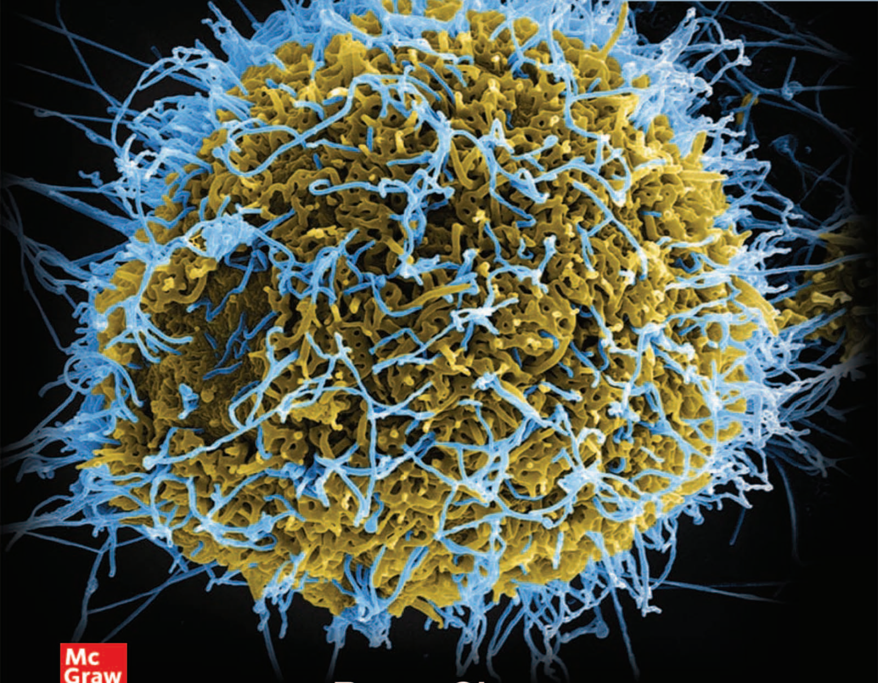
Talaro's Foundations in Microbiology

Eleventh Edition



McGraw Hill

Barry Chess

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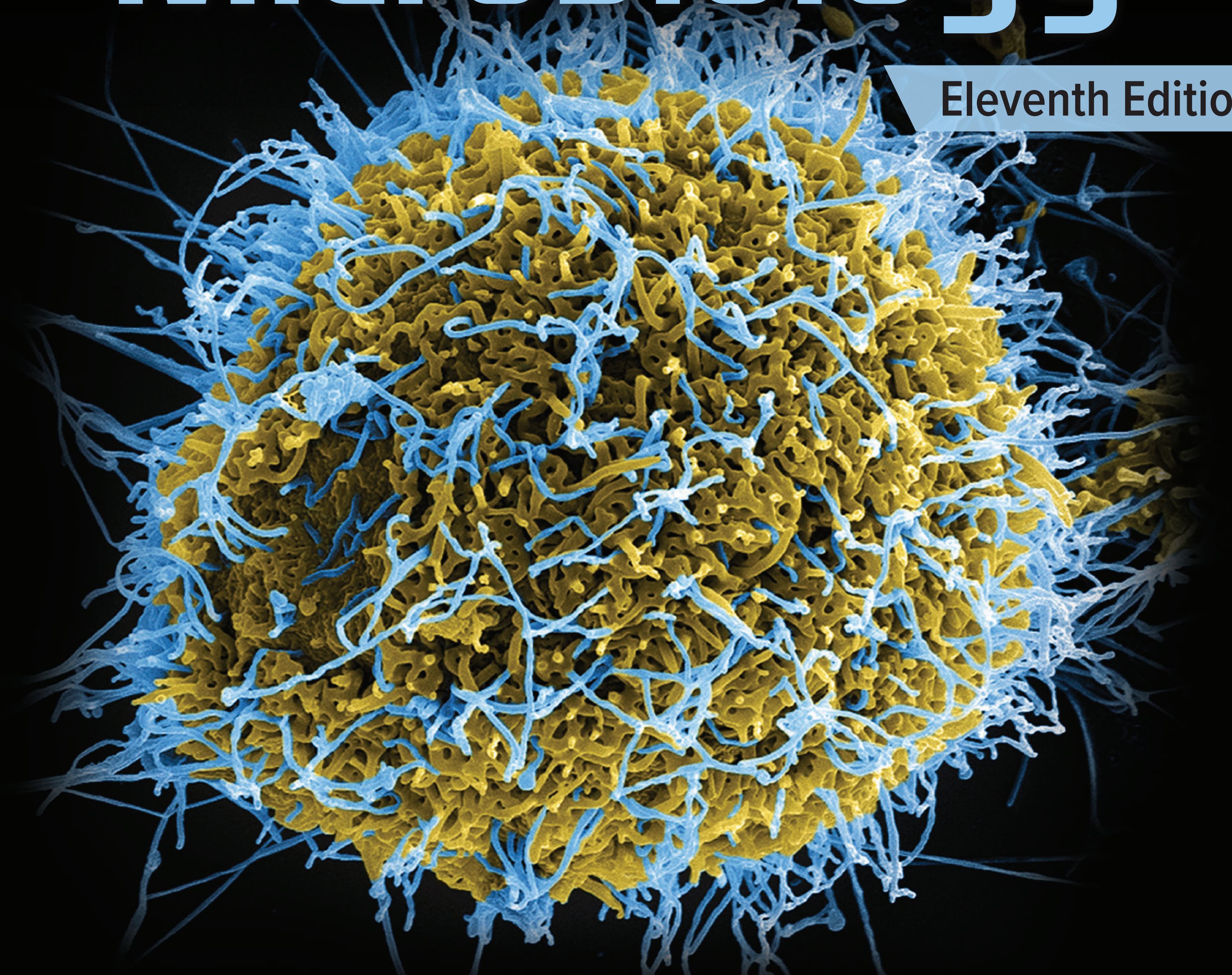

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FOUNDATIONS IN MICROBIOLOGY, ELEVENTH EDITION

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Brief Contents

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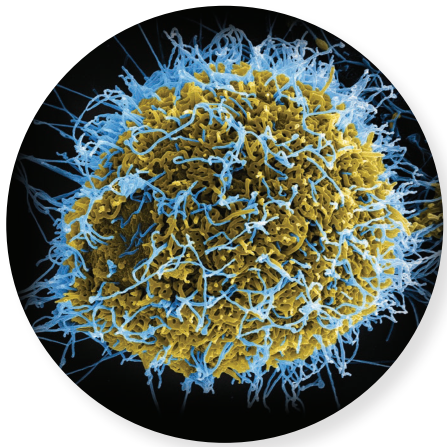
About the Author

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 worry about what needs to be cut from Chapter 17.

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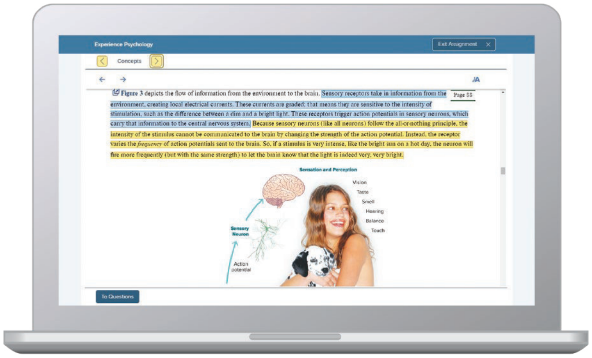

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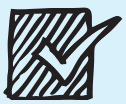

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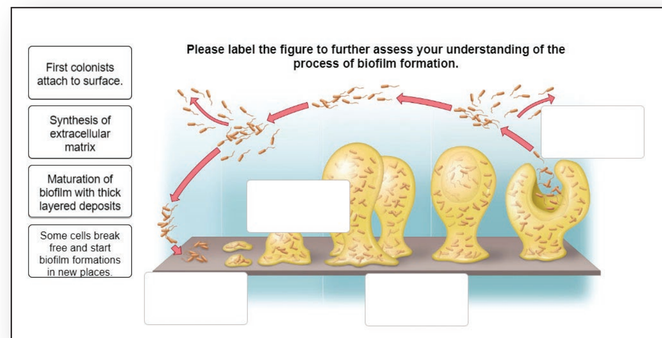

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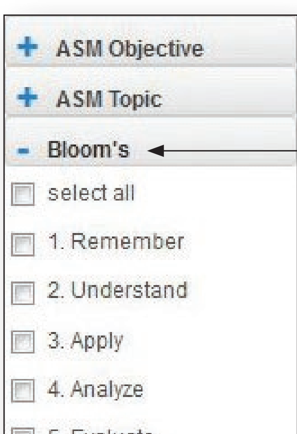

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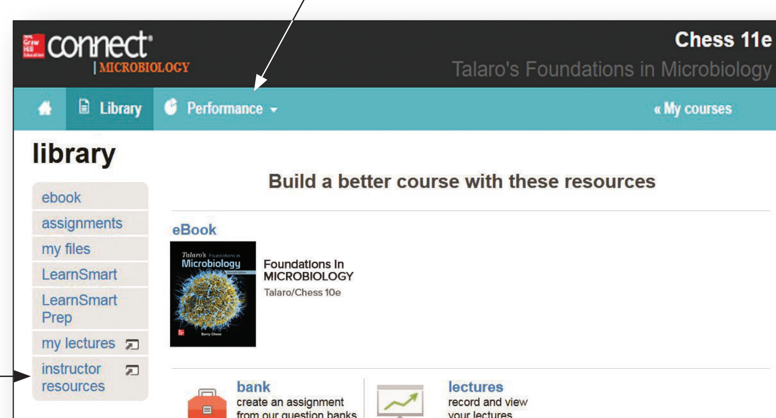

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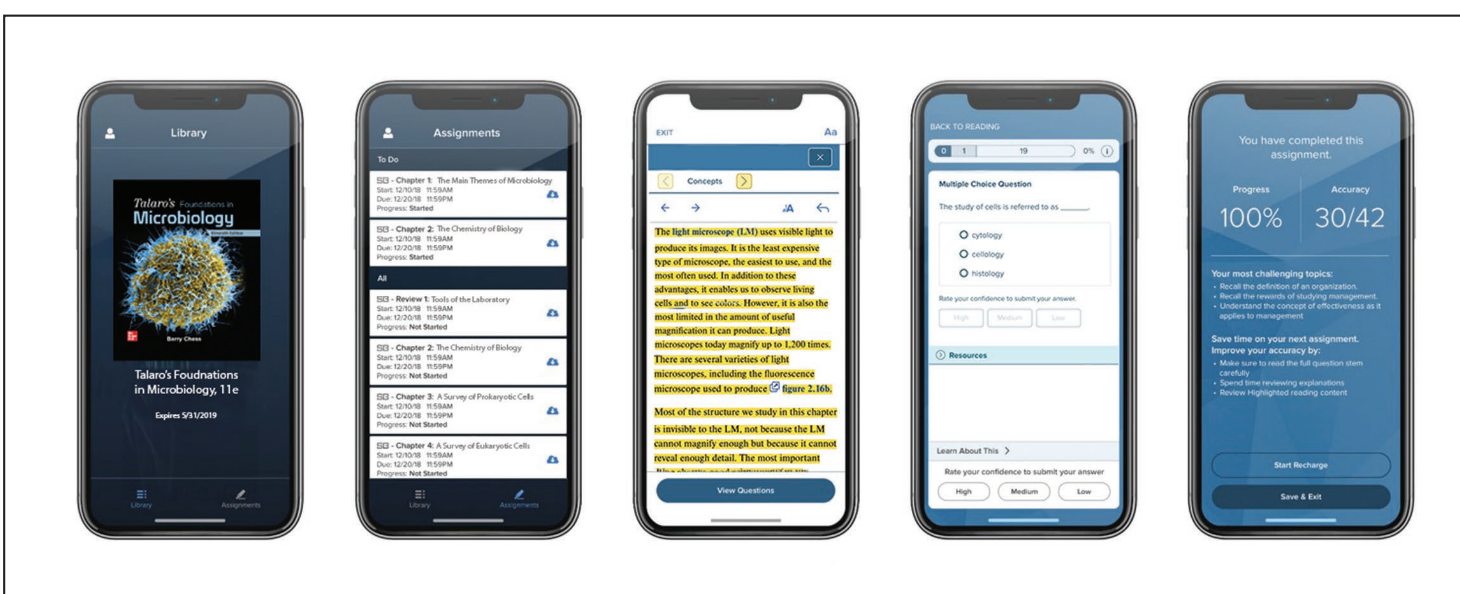
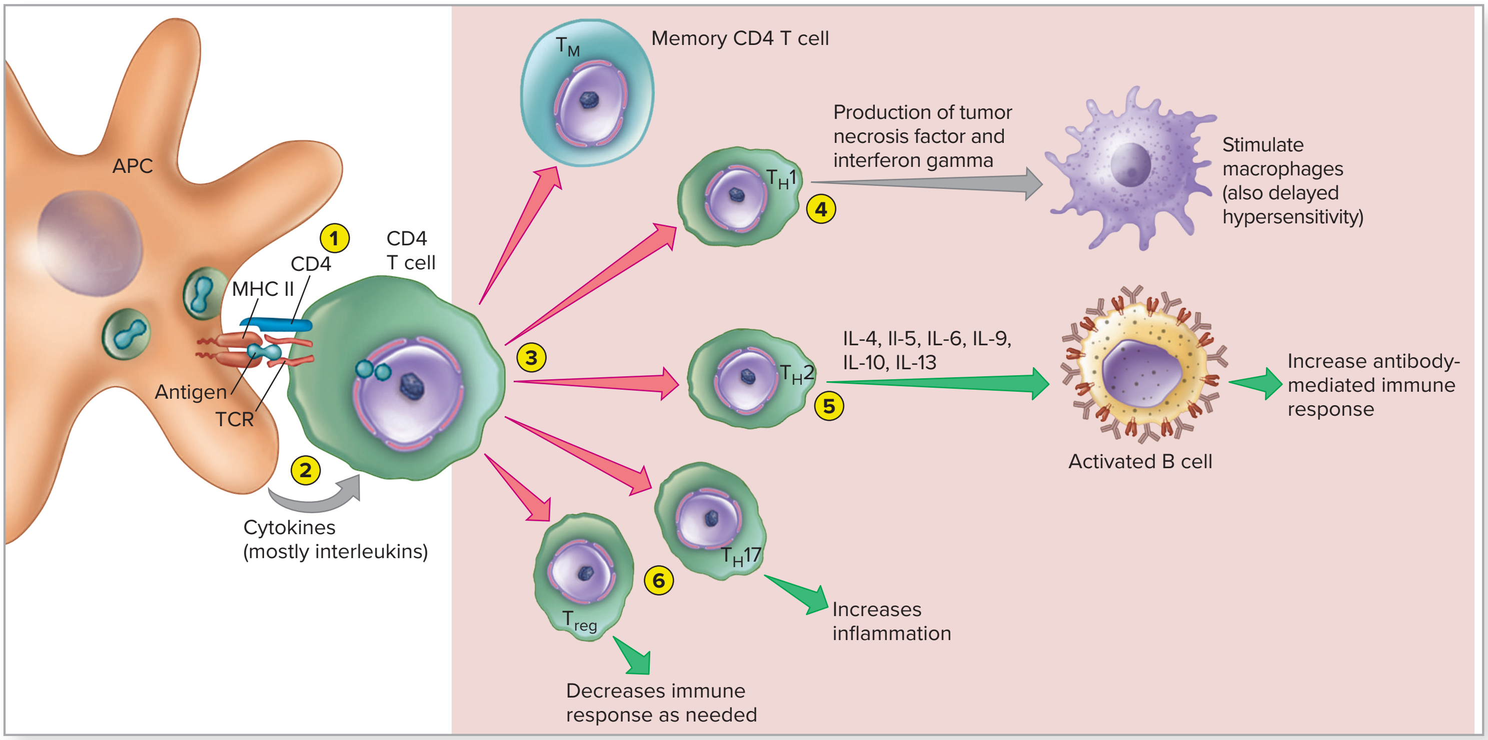


Designed for Today's Students

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 figures that break down complex processes into their simplest 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?*

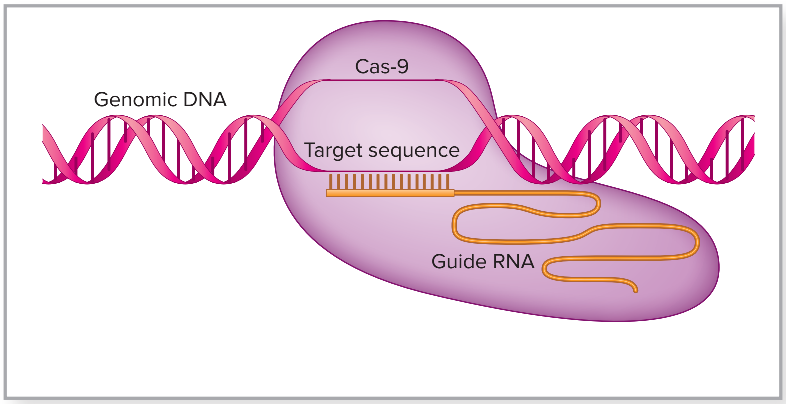
To continue the Case Study, go to Case Study Part 2 at the end of the chapter.

Plush Studios/Blend Images LLC

Illustrated to Increase Understanding

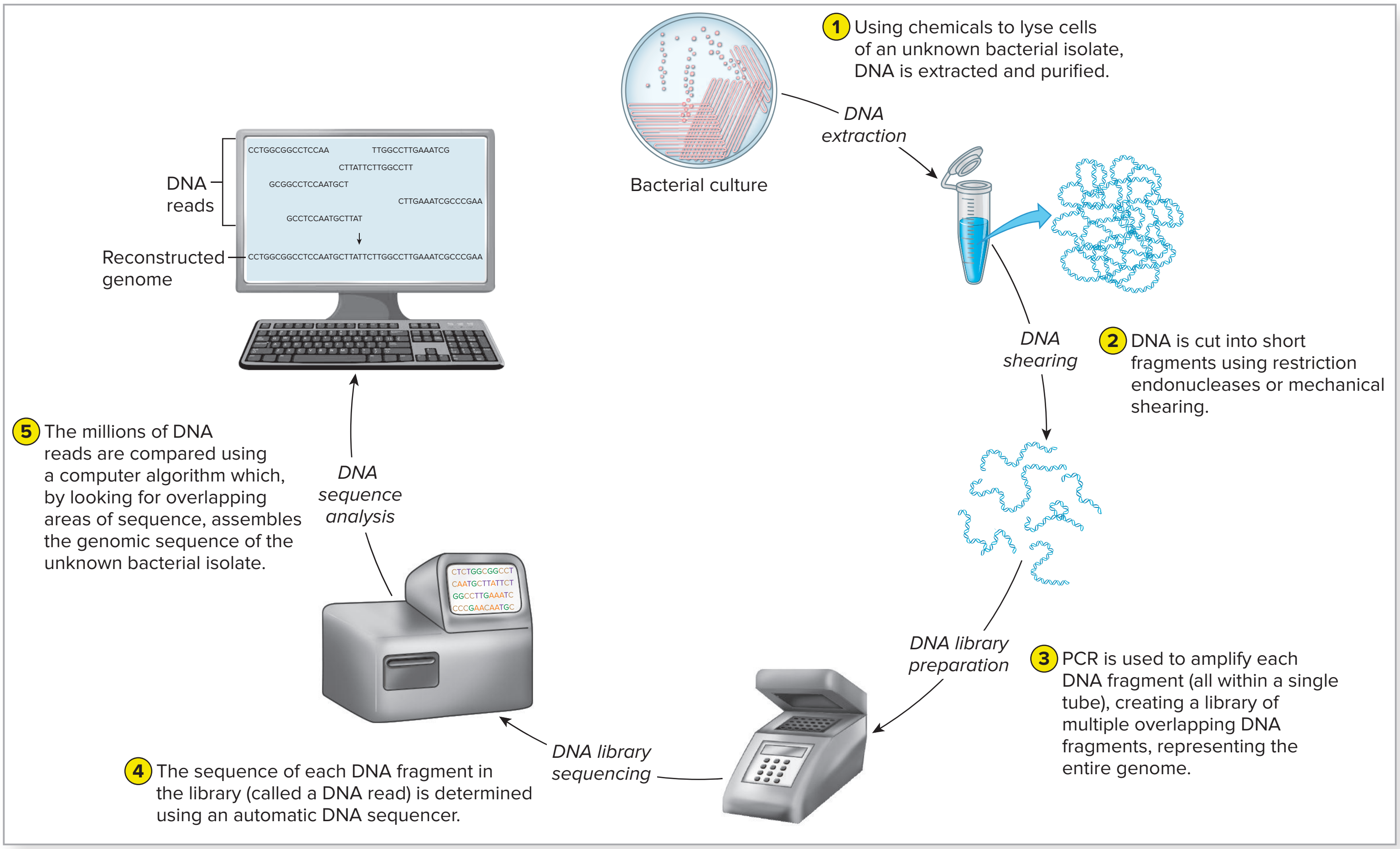
The author's experience and talent transform difficult concepts

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, has 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.

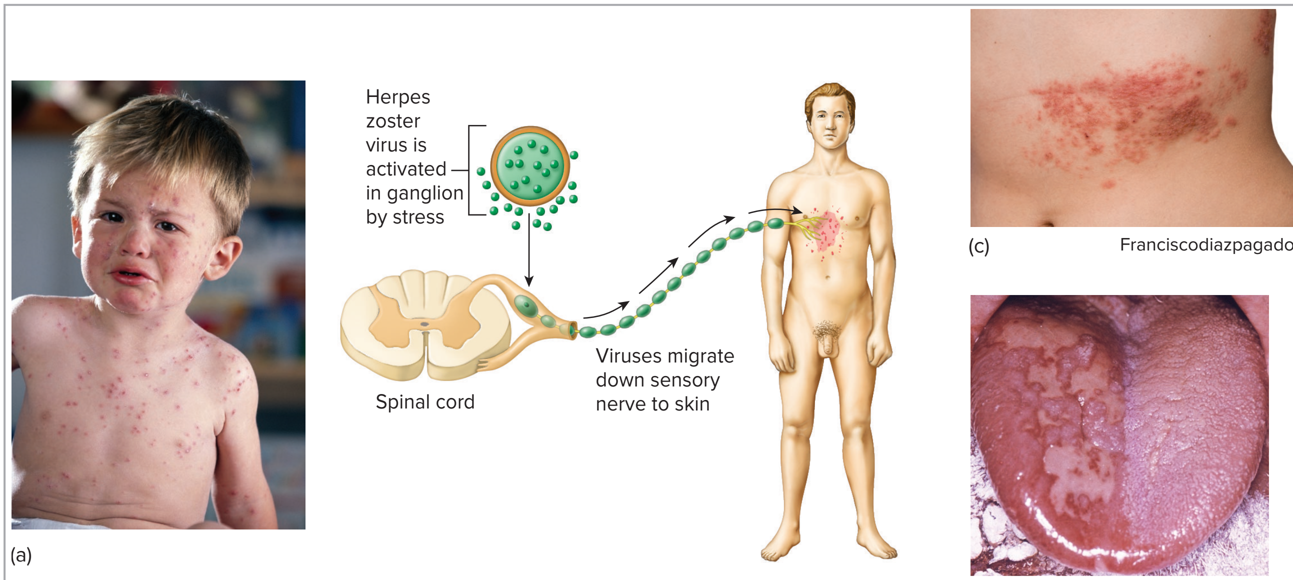


Process Figures

Process figures break down difficult concepts to more clearly illustrate their component parts. Each step is clearly numbered, making the 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



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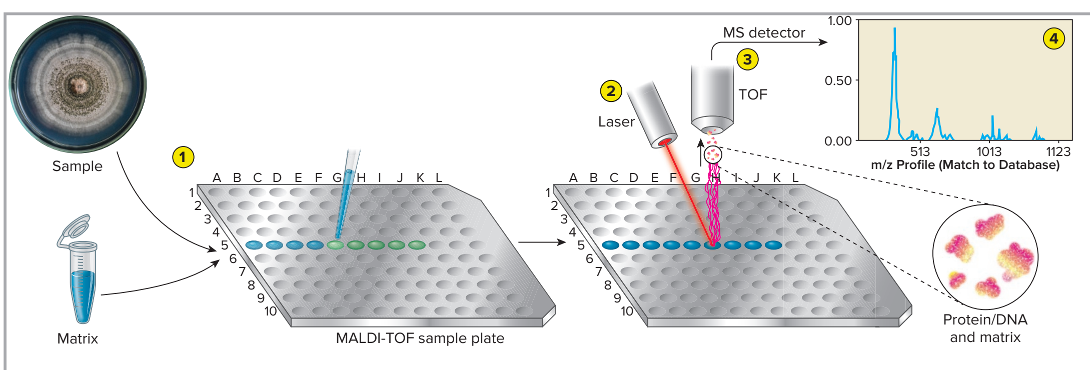
Modern Processes

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.

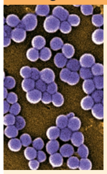
Practice SECTION 13.1

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).

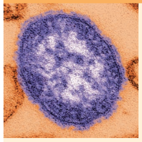
Primary Infections/Disease Local cutaneous infections include folliculitis, furuncles, and carbuncles, as well as bullous impetigo. Systemic infections include osteomyelitis, pneumonia, and endocarditis. A rare cause of meningitis. Diseases due to *S. aureus* toxins include food intoxication, scalded 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 2. Impetigo 3. Scalded skin syndrome 4. Osteomyelitis	Meningitis	1. Endocarditis 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				

Creating Lifelong Learners

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

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.

International symbol for breast feeding
Lukasz Stefanski/Shutterstock

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.

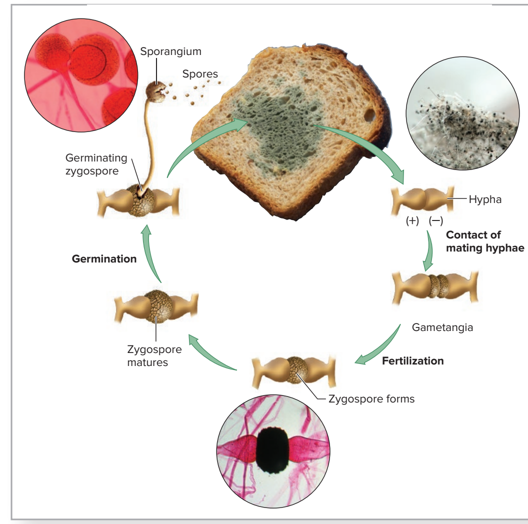
Footnotes

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

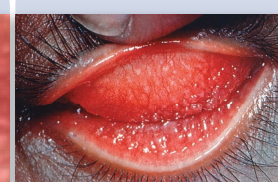
Line drawings combined with photos give students two perspectives: the realism of photos and the explanatory clarity of illustrations. The author chose this method of presentation to link what students read in the text to what they see in the laboratory, or even at home.



(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 Streptomycin Tobramycin Polymyxin Carbapenems Tetracyclines Sulfonamides Cephalosporins 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, is a condition similar to gut fermentation syndrome. SIBO occ when an overabundance of bacteria, rather than yeast, in the s intestine ferment carbohydrates. What product would be produ 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 answe NCLEX (National Council Licensure Examination).

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

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 th 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

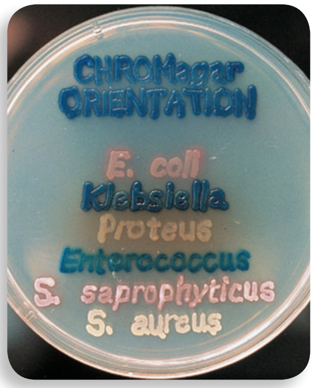
Critical thinking is the ability to reason and solve problems using facts and concepts. These questions can be approached from a number of angles and, in most cases, they do not have a single correct answer.

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

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

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.

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 following a case of 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 fourteenth 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 as a result of 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 *Trichinella* worms
- 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 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

Chapter 18
- New Case Study focuses on a case of methicillin-resistant *Staphylococcus aureus* in a professional football player
- Enhanced discussion of *S. aureus* virulence factors
- Discussion and photograph of rapid testing methods for *S. aureus* using antibodies
- Statistics have been updated to reflect current epidemiological trends
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- The ability to produce biofilms has been added to the discussion of streptococcal virulence
- New discussion of group B *Streptococcus*
- Clinic Case concerning group B streptococcal infection in an infant after the mother's ingestion of dried placenta capsules
- Seventeen new photographs

Chapter 19
- New Case Study concerning botulism acquired from pesto sauce purchased from a farmer's market
- *Clostridium difficile* has been reclassified as *Clostridioides difficile*
- Discussion of injection anthrax, which has become more prevalent, is now included in the chapter
- Clinic Case concerning neonatal tetanus caused by infection of the umbilicus
- New Pathogen Profile focusing on *Clostridium botulinum*
- Statistics have been updated to reflect current epidemiological trends
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Interferon-gamma release assays and nucleic acid testing for *M. tuberculosis* infections are discussed
- Clinic Case concerning an outbreak of tuberculosis spread by a zoo elephant
- Updated discussion of Hansen's disease
- Discussion of mycobacterial contamination of tattoos
- Ten new photographs and illustrations

Chapter 20
- New Case Study concerning *Brucella abortus* infection contracted from unpasteurized milk
- Clinic Case following an outbreak of legionellosis associated with Disneyland
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Statistics have been updated to reflect current epidemiological trends
- Seven new photographs and illustrations

Chapter 21
- Clinic Case following an incident of *Leptospira* infection after flooding of a college campus
- Clinic Case following an outbreak of *Campylobacter jejuni* linked to puppies
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Discussion of rapid identification methods for the detection of *Treponema pallidum*
- Statistics have been updated to reflect current epidemiological trends
- Six new photographs and illustrations

Chapter 22
- Clinic Case following an outbreak of fungal meningitis linked to contaminated steroid injections
- A discussion and figure concerning rapid identification of fungal specimens using matrix-assisted laser desorption/ionizing time of flight (MALDI-TOF) has been added
- Clinic Case concerning an outbreak of mucormycosis among organ transplant recipients has been added
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Statistics have been updated to reflect current epidemiological trends
- Four new photographs and illustrations

Chapter 23
- New Case Study concerning the first human infection with *Thelazia gulosa* (cattle eye worm)
- The guidelines for antiprotozoan drugs have been updated
- Clinic Case following a pair of *Naegleria fowleri* (the "brain-eating amoeba") linked to the use of neti pots
- A discussion of the RTS,S vaccine for malaria has been added
- A new table listing the major worms and the organs they affect has been added
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Statistics have been updated to reflect current epidemiological trends
- Seven new photographs and illustrations

Chapter 24
- A new table listing the major DNA viruses, infections, and common reservoirs has been added
- Clinic Case following an outbreak of adenovirus in a nursing and rehabilitation center
- Vaccination against and treatment of varicella-zoster infection have been updated
- Vaccine recommendations for hepatitis B have been updated
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Statistics have been updated to reflect current epidemiological trends
- Ten new photographs and illustrations

Chapter 25
- A new table listing the major RNA viruses, infections, and common reservoirs has been added

- Recommendations for vaccine against, and treatment of, influenza have been updated
- A new discussion, and images, of Ebola and Marburg viruses has been added
- The discussion of HIV treatment has been expanded and clarified
- A new table lists the most current anti-HIV medications and their modes of action
- Pathogen Profiles have been augmented to include the effect of pathogens on organ systems
- Clinic Case follows the means used to combat an outbreak of hepatitis A in San Diego, California
- Statistics have been updated to reflect current epidemiological trends
- Sixteen new photographs and illustrations

Chapter 26

- Clinic Case following a boil water notice incident in Frazier Park, California
- Four new photographs and illustrations

Chapter 27

- Clinic Case following an outbreak of botulism affecting inmates after the ingestion of prison-made wine (pruno)
- Discussion of wastewater treatment has been enhanced
- Statistics have been updated to reflect current epidemiological trends
- Six 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 wrote a book." Because writing a book is most definitely a team sport. And thank-yous 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. Extra special thanks to Anna R. Oller (University of Central Missouri) and Elizabeth Co, PhD. (Boston University) for their comments on parts of the early manuscript.

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, and 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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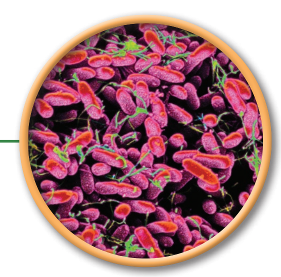
JT Thomas

Cathy Yeulet/amenic181/123RF



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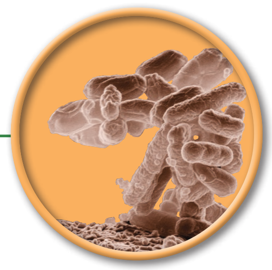

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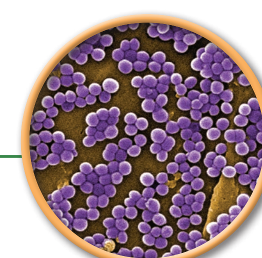

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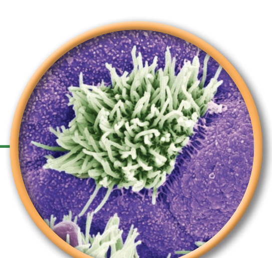

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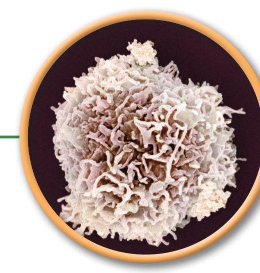

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CHAPTER 16


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CHAPTER 17


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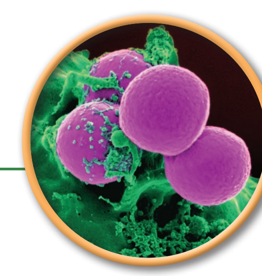
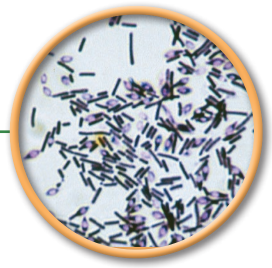
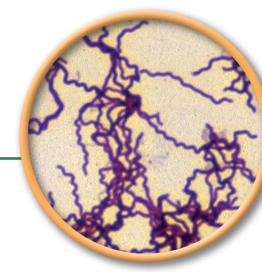
CHAPTER 18


Source: National Institute of Allergy and Infectious Diseases



Richard Gross/McGraw-Hill Education

Source: Janice Haney Carr/Bette Jensen/CDC



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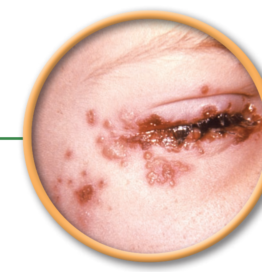
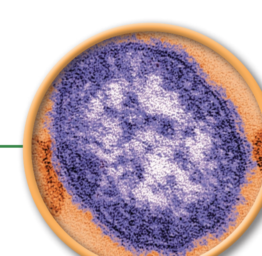


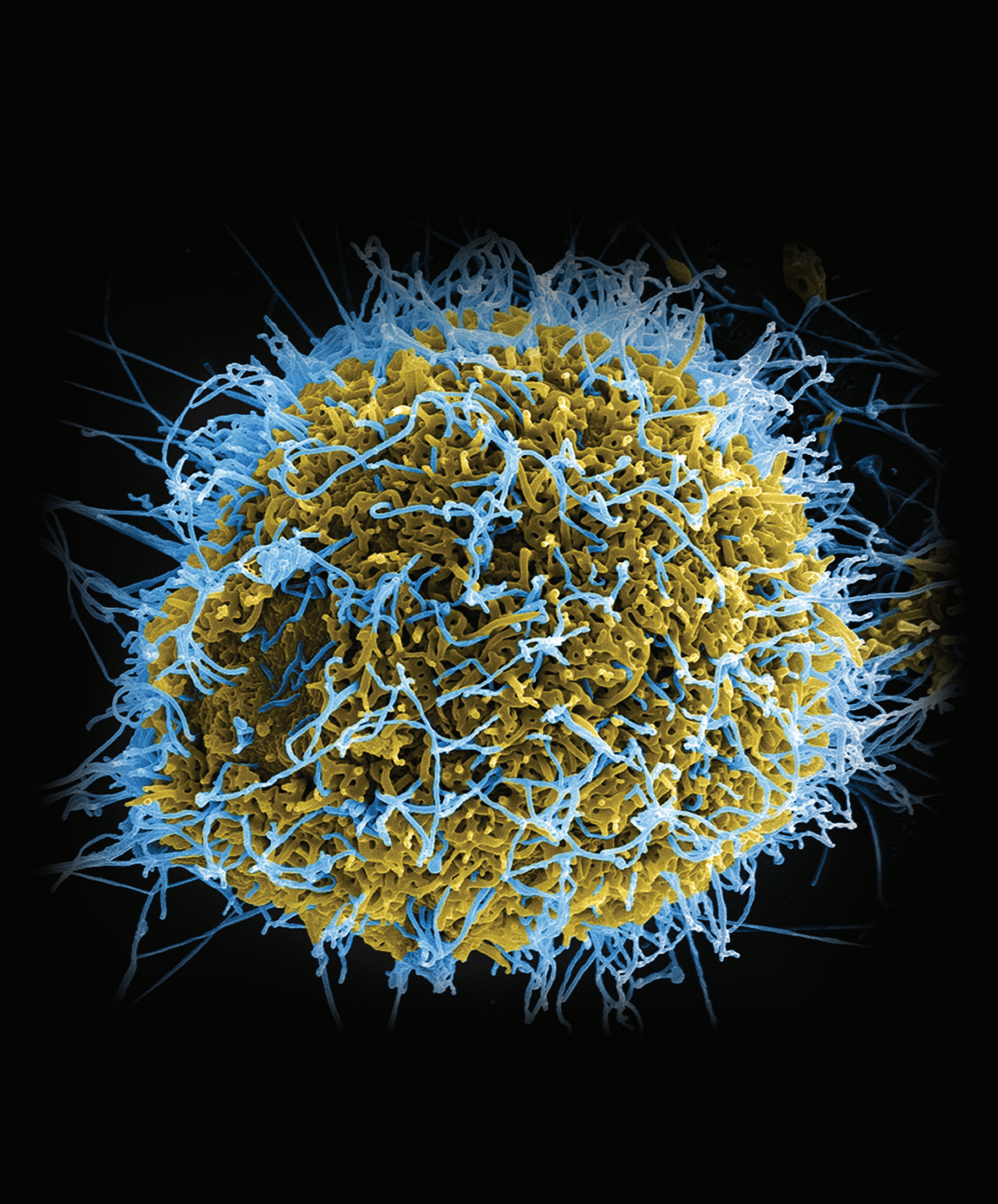
Source: CDC

CHAPTER 25

The RNA Viruses that Infect Humans 804



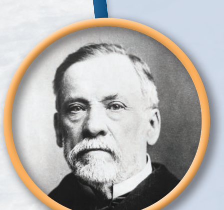
Source: Cynthia Goldsmith/CDC



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.

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

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* *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

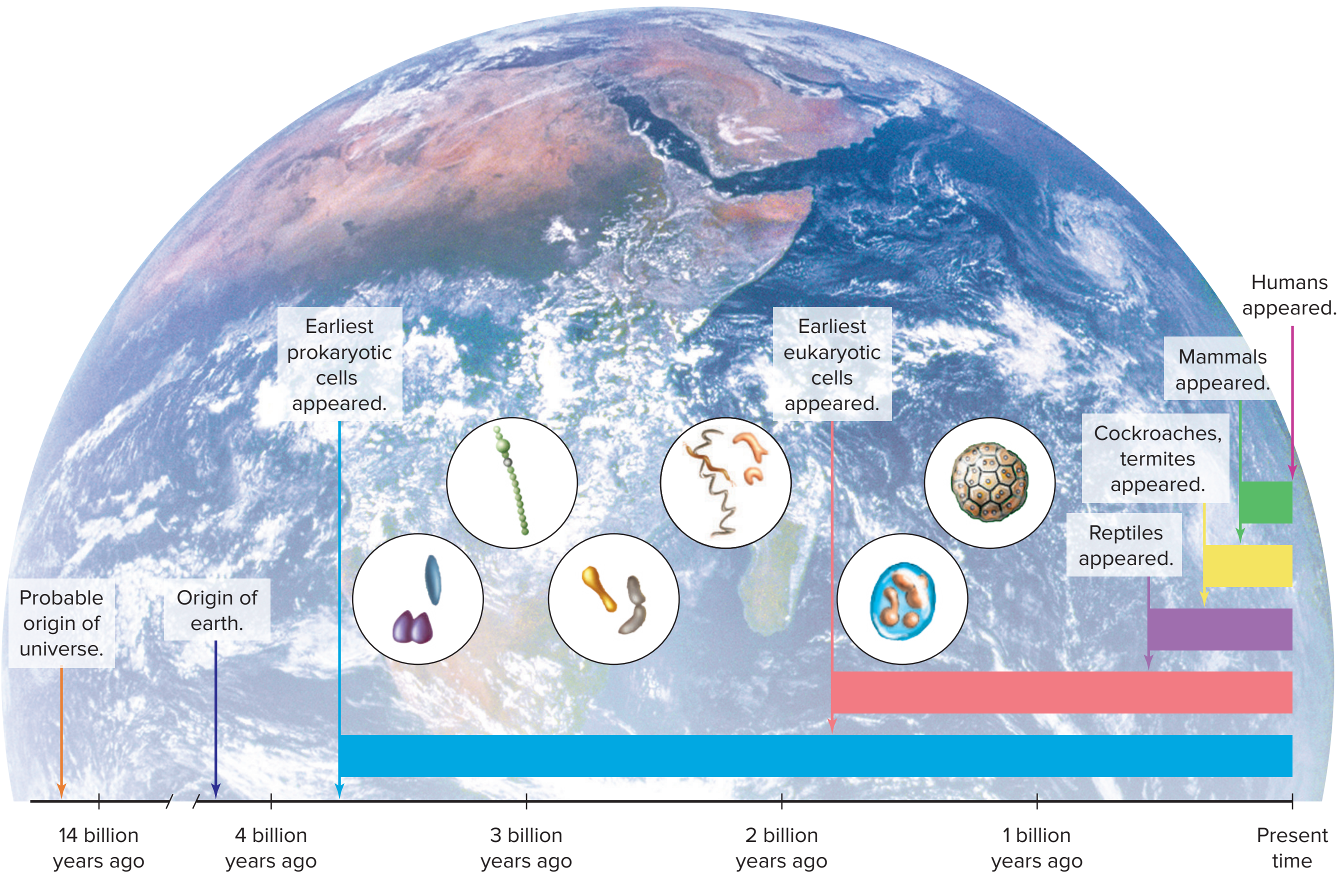


Figure 1.1 **Evolutionary time line.** The first simple prokaryotes appeared on earth approximately 3.5 billion years ago, and the first eukaryotes arose about 2 billion years ago. Although these appearances seem abrupt, hundreds of millions of years of earth's history passed while they were evolving 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.

* *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.

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-

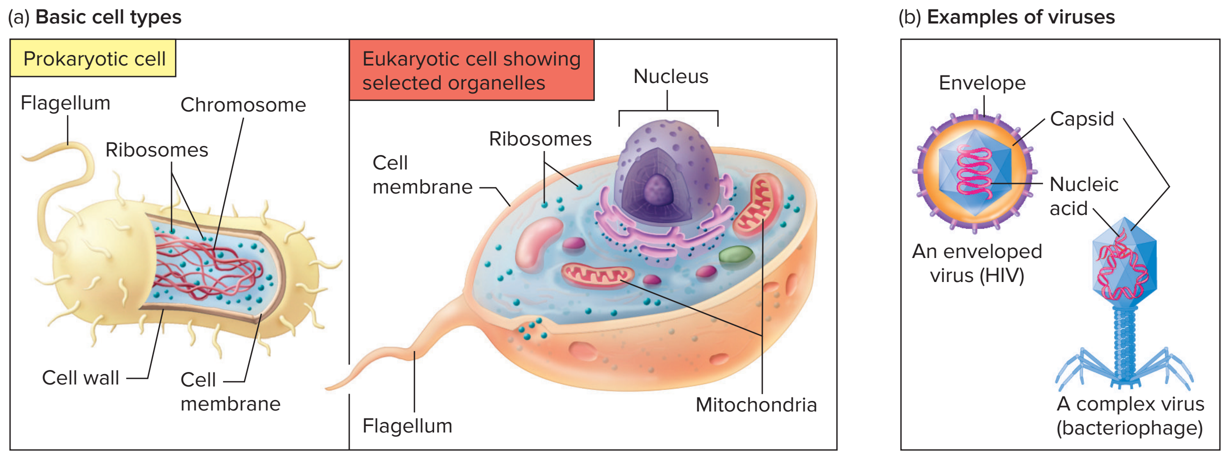
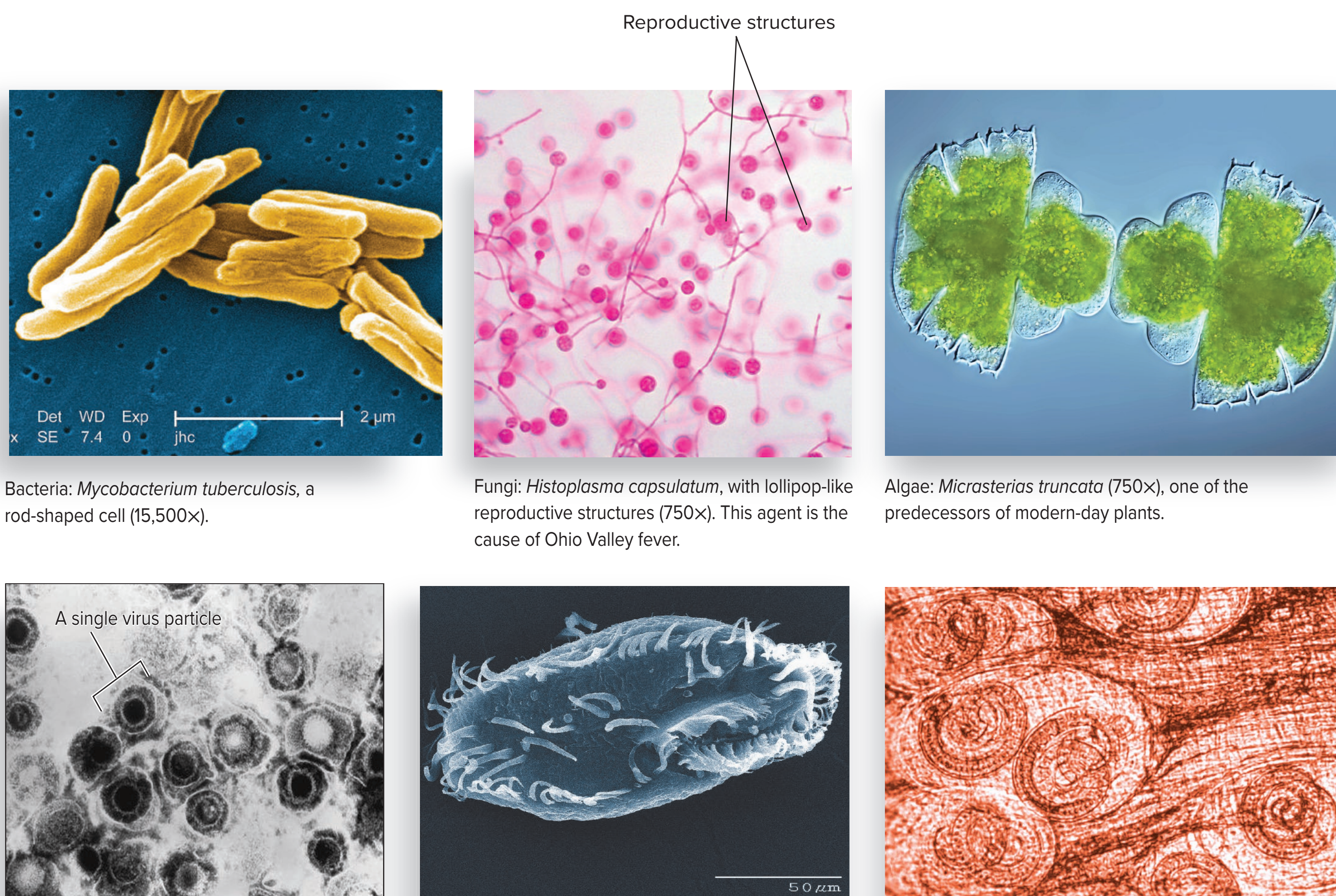


Figure 1.2 **Basic structure of cells and viruses. (a)** Comparison of a prokaryotic cell and a eukaryotic cell. **(b)** Two examples of viruses. These cell types and viruses are discussed in more detail in chapters 4, 5, and 6.



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.

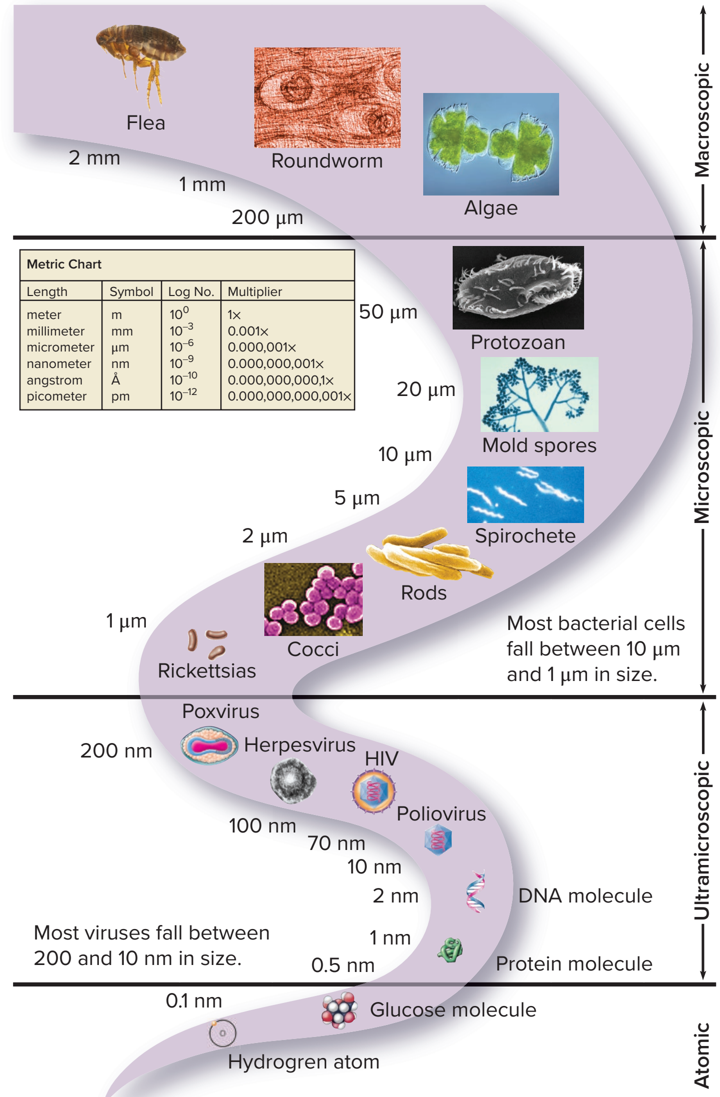
Noncellular Pathogenic Particles—Viruses and Prions

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.



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

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*)**.

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 Toledo, 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.

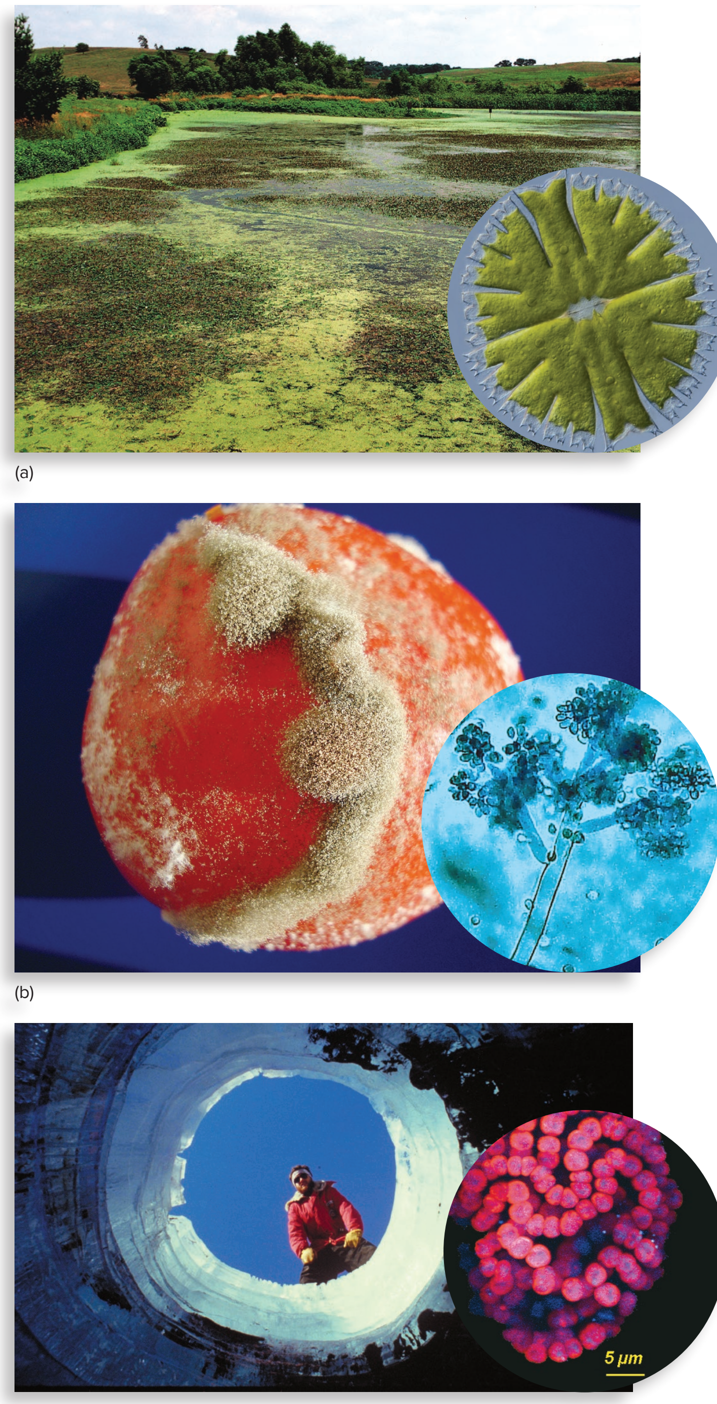


Figure 1.5 A microscopic wonderland. (a) A summer pond is heavily laden with surface scum that reveals several different types of green algae called desmids (*Micrasterias rotata,* 600×). **(b)** A rotting tomato being invaded by a fuzzy forest of mold. The fungus is *Botrytis,* a common decomposer of 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

Practice SECTIONS 1.1–1.2

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

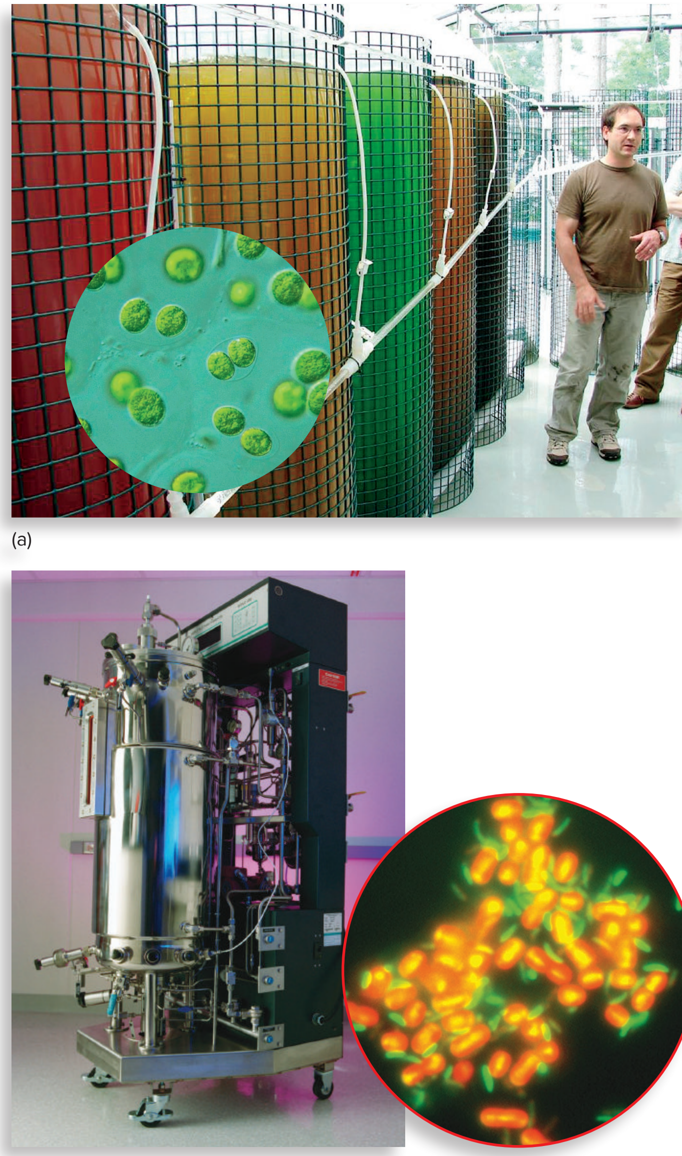
1.3 Human Use of Microorganisms

Learn

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

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

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



(a)

(b)

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

(a): *Source:* Christopher Botnick/NOAA; (a, inset): Yuuji Tsukii, Protist Information Server; (b & b, inset): *Source:* Pacific Northwest National Laboratory.

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

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

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

Another way of tapping into the unlimited potential of microorganisms is the relatively new science of **bioremediation.*** This process introduces microbes into the environment to restore stability or to clean up toxic pollutants. Bioremediation is required to control the massive levels of pollution that result from human activities. Microbes have a surprising capacity to break down chemicals that would be harmful to other organisms. Agencies and companies have developed microbes to handle oil spills and detoxify sites contaminated with heavy metals, pesticides, and even radioactive wastes **(figure 1.6*b*).** The solid waste disposal industry is focusing on methods for degrading the tons of garbage in landfills, especially plastics and paper products. One form of bioremediation that has been in use for some time is the treatment of water and sewage. With clean freshwater supplies dwindling worldwide, it will become even more important to find ways to reclaim polluted water.

1.4 Microbial Roles in Infectious Diseases

Learn

7. Review the roles of microorganisms as parasites and pathogens that cause infection and disease.

8. Define what is meant by emerging and reemerging diseases.

It is important to remember that the large majority of microorganisms are relatively harmless, have quantifiable benefits to humans and the environment, and in many cases are essential to life as we know it. They are free living and derive everything they need to survive from the surrounding environment. Much of the time they form cohesive communities with other organisms, sharing habitat and nutrients. Examples include the natural partnerships that are found in symbioses and biofilms.[3]

Some microbes have adapted to a non–free-living lifestyle called parasitism. A **parasite** lives in or on the body of a larger organism called the **host** and derives most of its sustenance from that host. A parasite's actions generally damage the host through infection and disease. Another term that can be used to specify this type of microbe is **pathogen.***

Humanity is plagued by nearly 2,000 different pathogens that can cause various types of disease. Infectious diseases still devastate human populations worldwide, despite significant strides in understanding and treating them. The most recent estimates from the World Health Organization (WHO) point to around 10 billion infections of all types across the world every year. There are more infections than people because many people acquire more than one infection. Infectious diseases are also among the most common causes of death in much of humanity, and they still kill a significant percentage of the U.S. population. The worldwide death toll from infections is about 13 million people per year, and 90% of the deaths are caused by just six infectious agents. **Table 1.2** illustrates the toll of some common infectious diseases, while **figure 1.7** compares the causes of death between countries that differ significantly in socioeconomic levels. It is quite evident which world inhabitants suffer the most from infectious diseases. **Table 1.3** displays the number of people affected by what are commonly known as neglected tropical diseases (NTDs), a collection of conditions that thrive among the world's poorest populations and receive far too little attention. Most NTDs are easily treatable with drugs or preventable with vaccines.

Those hardest hit are residents in countries where access to adequate medical care is lacking. One-third of the earth's 7 billion inhabitants live on less than $1 per day, are malnourished, are not fully immunized, and have no access to drugs. Take the case of malaria, caused by a microorganism transmitted by mosquitoes, which kills 1 to 2 million people every year worldwide. Currently the most effective way for citizens of developing countries to avoid

TABLE 1.2 Worldwide Morbidity and Mortality of Common Diseases*

Disease	New Cases per Year	Deaths per Year
Influenza	3–5 million cases of severe illness	250,000–500,000
Typhoid fever	21,000,000	200,000
Measles	20,000,000	145,700
HIV/AIDS	2,300,000	1,500,000
Dengue fever	96,000,000	22,000
Shigellosis	80,000,000–165,000,000	600,000
Viral hepatitis (A and B)	380,000,000	1,280,000
Malaria	200,000,000	627,000
Tuberculosis	9,000,000**	1,500,000

*Estimates from most recent CDC and World Health Organization statistics.

**As many as 2,000,000,000 people are believed to carry the tuberculosis bacterium, most as long-term carriers.

Source: Data from World Health Organization.

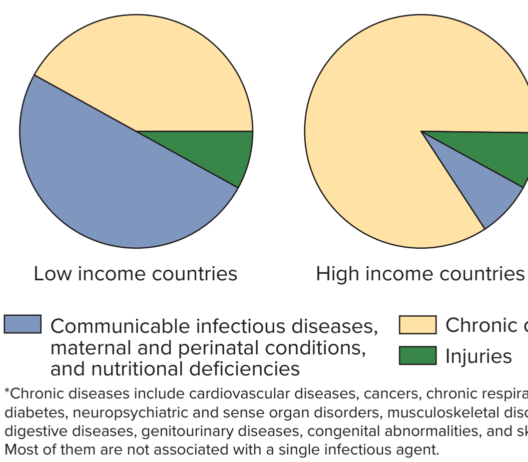


Figure 1.7 The burden of infectious disease. As the average income of a country increases, the risk of death from infectious disease decreases dramatically. Chronic diseases, many of which occur later in life, take a much greater toll in developed countries.

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

3. A biofilm is a complex network of microbes and their secretions that form in most natural environments, discussed further in chapter 4.

* *pathogen* (path′-oh-jen) Gr. *pathos,* disease, and *gennan,* to produce. Disease-causing agents.

TABLE 1.3 Neglected Tropical Diseases

Disease	Number of Cases
Ascariasis	1,000,000,000
Hookworm infection	700,000,000
Onchocerciasis (river blindness)	37,000,000
Lymphatic filariasis	120,000,000
Schistosomiasis	240,000,000
Trachoma	40,000,000
Trichuriasis	800,000,000

infection is to sleep under a bed net, because the mosquitoes are most active in the evening. Yet even this inexpensive solution is beyond the reach of people in many developing countries who cannot afford the $3 to $5 for nets to protect their family. Fortunately for many countries in the malaria zone, several international organizations have collaborated to provide special insecticide-treated nets that can help lower the rate of infections.

The Changing Specter of Infectious Diseases

Great progress was made in the mid-1900s as the introduction of antibiotics in the 1940s and a lengthening list of vaccines for preventing numerous diseases caused many medical experts to declare a premature victory. For a short time, there was a sense that infectious diseases were going to be completely manageable. Because humans are constantly interacting with microbes, we serve as a handy incubator for infectious diseases, both those newly recognized and older ones previously identified.

Emerging diseases are newly identified conditions that are being reported in increasing numbers. Since 1980, at least 87 novel infectious agents have arisen within the human population. Some have been associated with a specific location, like the Ebola fever virus, named for the Ebola River, near which the disease was first seen, while other diseases are **pandemic,** meaning they spread across continents (human immunodeficiency virus, HIV, provides a perfect example). Still others cause **zoonoses,*** which are infectious diseases native to animals that can be transmitted to humans. One recent example is chikungunya virus, spread by mosquitoes to humans and other mammals. This virus traveled from the Caribbean to Florida in 2014. It is unclear how fast the virus will spread throughout the United States, as conditions become less favorable to the life cycle of mosquitoes as one moves north. Even more recently, Zika virus, which is spread by the same type of mosquito, **(figure 1.8)** has been detected within the United States.

Reemerging diseases are older, well-known diseases that are increasing in occurrence. Among the most common reemerging infectious diseases are tuberculosis (TB), influenza, malaria, cholera, and hepatitis B. Tuberculosis, which has been known since ancient times, still causes 8 million new infections and kills 1 million to 2 million people every year. As you will see, numerous factors play a part in the tenaciousness of infectious diseases, but fundamental to all of them is the formidable capacity of microbes to adapt to alterations in the individual, community, and environment.

* *zoonosis* (zoh″-uh-noh′-sis) Gr. *zoion,* animal, and *nosos,* disease. Any disease indigenous to animals transmissible to humans.

Figure 1.8 The *Aedes aegypti* mosquito is the vector for several emerging viral diseases. In this female mosquito, feeding on her photographer, blood can clearly be seen within the fascicle (feeding apparatus) and filling the distended abdomen of the mosquito. Because this species is found throughout the Americas, it is thought to be only a matter of time before the Zika, dengue, and chikungunya viruses are well established in the United States.
Source: Frank Hadley Collins, Dir. Center for Global Health and Infectious Diseases; University of ND/CDC

Altogether, government agencies are keeping track of more than 100 emerging and reemerging infectious diseases. Reemerging diseases demonstrate just how difficult it is to eradicate microbes and the diseases they cause, even though we are aware of them and often have drugs and vaccines to combat them. Only smallpox has been eliminated, although we are very close to eradicating polio. In fact, we continue to experience epidemics of childhood diseases that are usually preventable with vaccines. A prime example is measles—considered eliminated from the United States in 2000—which has reemerged as vaccination rates have declined.

A major contributing factor in the spread of disease is our increased mobility and travel, especially by air—an infected person can travel around the world before showing any symptoms of infection, carrying the infectious agent to many far-flung locations and exposing populations along the way, who in turn can infect their contacts. A second factor is the spread of diseases by vectors, living organisms such as fleas, ticks, or mosquitoes. Emerging viruses like chikungunya, dengue, and Zika are all spread by the *Aedes* mosquito, which is so aggressive it routinely follows people indoors to partake of a blood meal (figure 1.8). Other significant effects involve our expanding population and global food-growing practices. As we continue to encroach into new territory and wild habitats, there is potential for contact with emerging pathogens, as has been seen with Ebola fever, Lyme disease, and hantavirus pulmonary syndrome. Our agricultural practices can unearth microbes that were lying dormant or hidden. A bacterium carried in the intestine of domestic cattle, *Escherichia coli* O157:H7, the agent of a serious kidney disease, has been associated with hundreds of thousands of infections from food and water contaminated with cattle feces. Mass-produced fresh food can also travel around the world, infecting people along the way. Several large outbreaks of salmonellosis, shigellosis, and listeriosis have been traced to contaminated dairy, poultry products, and vegetables.

The incredible resistance of microbes also contributes to their continued spread. The emergence of drug-resistant "superbugs" has become a massive problem in medicine. Some forms of *Staphylococcus aureus* (MRSA) and *Mycobacterium tuberculosis* are resistant to so many drugs that there are few, and sometimes no, treatment choices left. As hard as we may try to manage microbes, we keep coming up against a potent reality, a sentiment summed up by the renowned microbiologist Louis Pasteur over 130 years ago when he declared, "Microbes will have the last word."

Microbial Roles in Noninfectious Disease

One of the most eye-opening discoveries has been that many diseases once considered noninfectious probably do involve microbial infection. Most scientists expect that, in time, a majority of chronic conditions will be linked to microbial agents. The most famous of these is gastric ulcers, now known to be caused by a bacterium called *Helicobacter* (see chapter 21). Diseases as disparate as type 1 diabetes, obsessive-compulsive disorder, and coronary artery disease have been linked to chronic infections with microorganisms. Even the microbiome, the collection of microorganisms we all carry with us even when healthy, has been shown to have a much greater effect on our health than was previously thought. Recent studies have linked changes in the microbiome population to metabolic syndrome, a collection of health conditions including high cholesterol, hypertension, high blood sugar levels, and excess fat, all of which can raise the risk of heart disease, stroke, and diabetes.

It seems that the golden age of microbiological discovery, during which all of the "obvious" diseases were characterized and cures or preventions were devised for them, should more accurately be referred to as the first golden age. We're now discovering the roles of microorganisms in hidden but slowly destructive diseases. These include female infertility caused by *Chlamydia* infection and malignancies such as liver cancer (hepatitis viruses) and cervical cancer (human papillomavirus). In fact, epidemiologists analyzing statistics on world cancer have estimated that one in six cancers can be associated with an infectious agent.

Another important development in infectious disease trends is the increasing number of patients with weakened defenses who are kept alive for extended periods. We are becoming more susceptible to infectious disease precisely because of advances in medicine. People are living longer and sick people are staying alive much longer than in the past, creating a population far more susceptible to what we might call "garden-variety" microbes.

Practice SECTIONS 1.3–1.4

7. Describe several ways the beneficial qualities of microbes greatly outweigh microbes' roles as infectious agents.
8. Look up in the index some of the diseases shown in table 1.2 and determine which ones could be prevented by vaccines or cured with drugs. Are there other ways (besides vaccines) to prevent any of these?
9. Distinguish between emerging and reemerging infectious diseases and explain what factors contribute to their development.

1.5 The Historical Foundations of Microbiology

Learn

9. Outline the major events in the history of microbiology, including the major contributors to the early development of microscopy, medical advances, aseptic techniques, and the germ theory of disease.
10. Explain the main features of the scientific method, and differentiate between inductive and deductive reasoning and between hypothesis and theory.

If not for the extensive interest, curiosity, and devotion of thousands of microbiologists over the last 300 years, we would know little about the microscopic realm that surrounds us. Many of the discoveries in this science have resulted from the prior work of men and women who toiled long hours in dimly lit laboratories with the crudest of tools. Each additional insight, whether large or small, has added to our current knowledge of life forms and processes. This section summarizes the prominent discoveries made in the past 300 years: microscopy, the rise of the scientific method, and the development of medical microbiology, including the germ theory and the origins of modern microbiological techniques. The table "Significant Events in Microbiology," found in **Online Appendix 2,** summarizes some of the pivotal events in microbiology from its earliest beginnings to the present.

The Development of the Microscope: Seeing Is Believing

It is likely that from the very earliest history, humans noticed that when certain foods spoiled, they became inedible or caused illness and yet other "spoiled" foods did no harm and even had enhanced flavor. Even several centuries ago, there was already a sense that diseases such as the black plague and smallpox were caused by some sort of transmissible matter. But the causes of such phenomena were obscure because the technology to study them was lacking. Consequently, they remained cloaked in mystery and regarded with superstition—a trend that led even well-educated scientists to believe in spontaneous generation **(1.1 Making Connections).**

True awareness of the widespread distribution of microorganisms and some of their characteristics was finally made possible by the development of the first microscopes. These devices revealed microbes as discrete entities sharing many of the characteristics of larger, visible plants and animals. Several early scientists fashioned magnifying lenses and microscopes, but these lacked the optical clarity needed for examining bacteria and other small, single-celled organisms. The most careful and exacting observations awaited the simple single-lens microscope hand-fashioned by **Antonie van Leeuwenhoek,** a Dutch linen merchant and self-made microbiologist.

During the late 1600s in Holland, Leeuwenhoek used his early lenses to examine the thread patterns of the draperies and upholstery he sold in his shop. Between customers, he retired to the workbench in the back of his shop, grinding glass lenses to ever-finer specifications. He could see with increasing clarity, but after a few years he became interested in things other than thread counts. He took rainwater from a clay pot, smeared it on his specimen holder, and peered at it through his finest lens. He found "animals appearing to me ten thousand times more than those which may be perceived in the water with the naked eye."

> **Quick Search**
> Search for "Through van Leeuwenhoek's Eyes: Microbiology in a Nutshell" on YouTube to watch a video inspired by Leeuwenhoek's world

He didn't stop there. He scraped plaque from his teeth, and from the teeth of volunteers who had never cleaned their teeth in their lives, and took a close look at that. He recorded: "In the said matter there were many very little living animalcules, very prettily a-moving . . . . Moreover, the other animalcules were in such enormous numbers, that all the water . . . seemed to be alive." Leeuwenhoek started sending his observations to the Royal Society of London, and eventually he was recognized as a scientist of great merit.

Leeuwenhoek constructed more than 250 small, powerful microscopes that could magnify up to 300 times **(figure 1.9)**. Considering that he had no formal training in science and that he was the first person ever to faithfully record this strange new world, his descriptions of bacteria and protozoa (which he called "animalcules") were astute and precise. Because of Leeuwenhoek's extraordinary contributions to microbiology, he is sometimes considered the father of bacteriology and protozoology.

From the time of Leeuwenhoek, microscopes became more complex and improved, with the addition of refined lenses, a condenser, finer focusing devices, and built-in light sources. The prototype of the modern compound microscope, in use from about the mid-1800s, was capable of magnifications of 1,000 times or more, largely because it had two sets of lenses for magnification. Even our modern laboratory microscopes are not greatly different in basic structure and function from those early microscopes. The technical characteristics of microscopes and microscopy are a major focus of chapter 3.

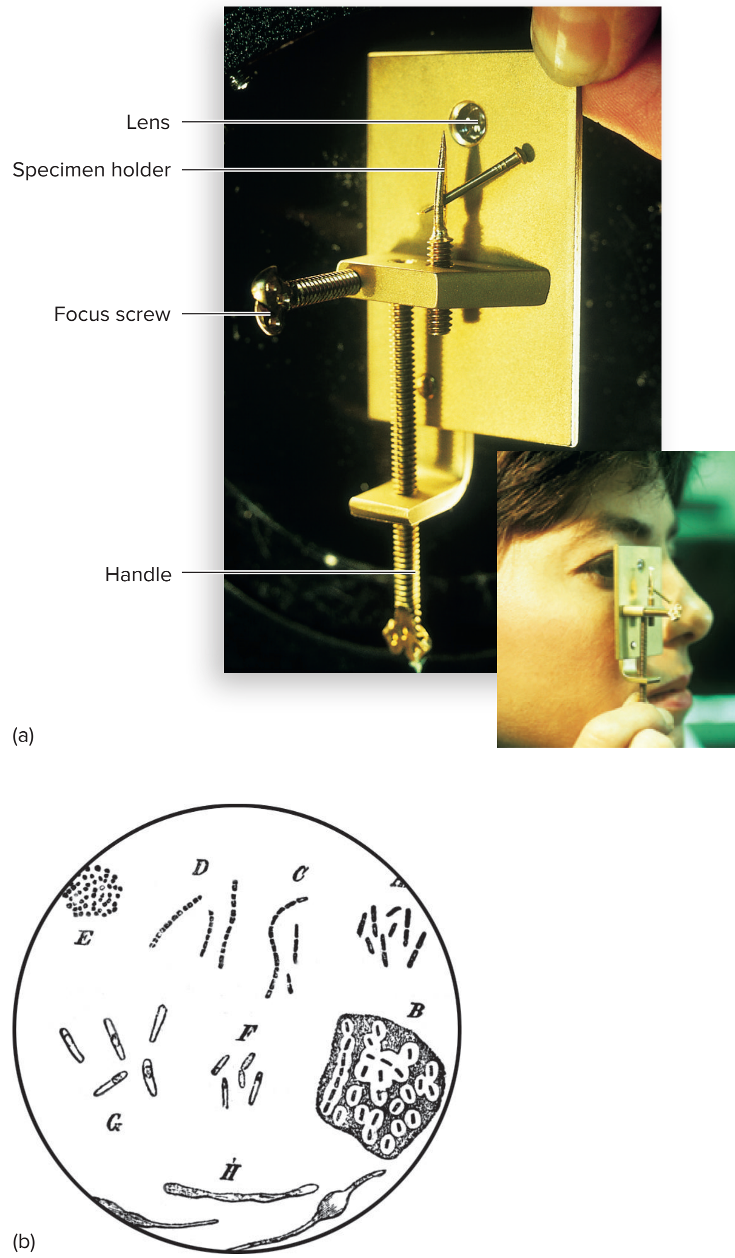


Figure 1.9 Leeuwenhoek's microscope. **(a)** A brass replica of a Leeuwenhoek microscope and how it is held (inset). **(b)** Early illustrations of bacterial cells from a sample of milk, magnified about 300×. These drawings closely resemble those Leeuwenhoek made of his animalcules.
(a): Kathy Park Talaro; (a, inset): Pasadena City College/Kathy Park Talaro

The Scientific Method and the Search for Knowledge

The research that led to acceptance of biogenesis provides us with one example of the early development of science-based thought. Over the next few sections we will glimpse other important milestones in the development of the scientific method, such as vaccination, germ theory, asepsis, and Koch's postulates. The impact of science is so pervasive that you may not realize how much of our everyday life is built upon applications of the scientific method. Vaccines, antibiotics, space travel, computers, medical diagnosis, and DNA testing exist primarily because of the work of thousands of scientists doing objective observations and collecting evidence that is measurable, can be expressed quantitatively, and is subject to critical analysis.

The information obtained through the scientific method is explanatory and predictive. It aims to explain how and why phenomena occur and to predict what is expected to happen under known conditions.

How do scientists apply the scientific method? In the **deductive reasoning** approach, a scientist uses general observations of some phenomenon to develop a set of facts to explain that phenomenon—that is, they *deduce* the facts that can account for what they have observed. This early explanation is considered a **hypothesis,** and however tentative it may start out, it is still based on scientific thought rather than subjective beliefs that come from superstition or myth. A valid hypothesis will allow for experimentation and testing and can be shown to be false. An example of a workable

1.1 MAKING CONNECTIONS

The Fall of Superstition and the Rise of Microbiology

For thousands of years, people believed that certain living things arose from vital forces present in nonliving or decomposing matter. This ancient idea, known as **spontaneous generation,** was continually reinforced as people observed that meat left out in the open soon "produced" maggots, that mushrooms appeared on rotting wood, that rats and mice emerged from piles of litter, and that other magical phenomena occurred. Though some of these early ideas seem quaint and ridiculous in light of modern knowledge, we must remember that, at the time, mysteries in life were accepted and the scientific method was not widely practiced.

Even after single-celled organisms were discovered during the mid-1600s, the idea of spontaneous generation persisted. Some scientists assumed that microscopic beings were an early stage in the development of more complex ones.

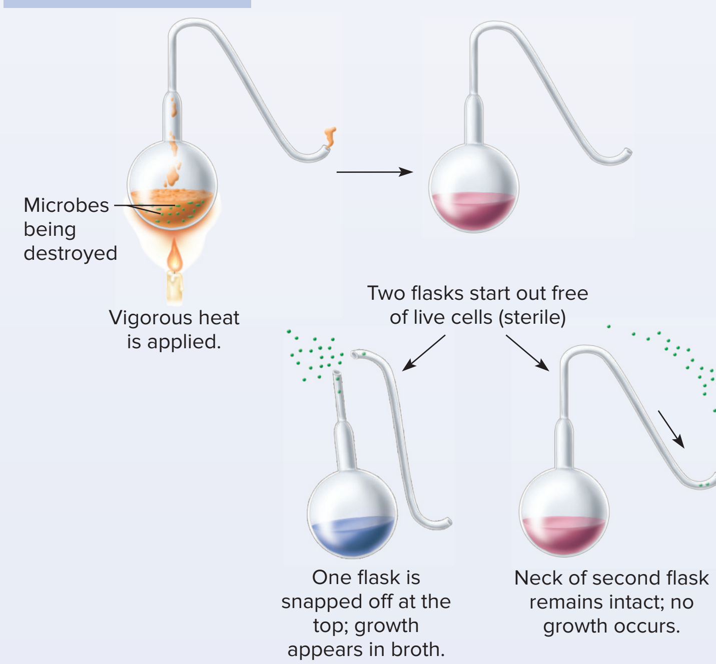
Over the subsequent 200 years, scientists waged an experimental battle over the two hypotheses that could explain the origin of simple life forms. Some tenaciously clung to the idea of **abiogenesis*** which embraced spontaneous generation. On the other side were advocates of **biogenesis,*** saying that living things arise only from others of their same kind. There were serious proponents on both sides, and each side put forth what appeared on the surface to be plausible explanations of why their evidence was more correct. Gradually the abiogenesis hypothesis was abandoned as convincing evidence for biogenesis continued to mount. The following series of experiments were among the most important in finally tipping the balance.

Some of the important variables to be considered in testing the hypotheses were the effects of nutrients, air, and heat and the presence of preexisting life forms in the environment. One of the first people to test the spontaneous generation theory was **Francesco Redi** of Italy. He conducted a simple experiment in which he placed meat in a jar and covered the jar with fine gauze. Flies gathering at the jar were blocked from entering and thus laid their eggs on the outside of the gauze. The maggots subsequently developed without access to the meat, indicating that maggots were the offspring of flies and did not arise from some "vital force" in the meat. This and related experiments laid to rest the idea that more complex animals such as insects and mice developed through abiogenesis, but it did not convince many scientists of the day that simpler organisms could not arise in that way.

The Frenchman **Louis Jablot** reasoned that even microscopic organisms must have parents, and his experiments with infusions (dried hay steeped in water) supported that hypothesis. He divided an infusion that had been boiled to destroy any living things into two containers: a heated container that was closed to the air and a heated container that was freely open to the air. Only the open vessel developed microorganisms, which he presumed had entered in air laden with dust. Regrettably, the validation of biogenesis was temporarily set back by **John Needham,** an Englishman who did similar experiments using mutton gravy. His results were in conflict with Jablot's because both his heated and unheated test containers teemed with microbes. Unfortunately, his experiments were done before the realization that heat-resistant microbes are not usually killed by mere boiling. Apparently Jablot had been lucky; his infusions were sterile.

Then, in the mid-1800s, the acclaimed microbiologist **Louis Pasteur** entered the arena. He had recently been studying the roles of microorganisms in the fermentation of beer and wine, and it was clear to him that these processes were brought about by the activities of microbes introduced into the beverage from air, fruits, and grains. The methods he used to discount abiogenesis were simple yet brilliant.

Pasteur's Experiment



To further clarify that air and dust were the source of microbes, Pasteur filled flasks with broth and fashioned their openings into elongate, swan-neck–shaped tubes. The flasks' openings were freely open to the air but were curved so that gravity would cause any airborne dust particles to deposit in the lower part of the necks. He heated the flasks to sterilize the broth and then incubated them. As long as the flask remained intact, the broth remained sterile, but if the neck was broken off so that dust fell directly down into the container, microbial growth immediately commenced.

Pasteur summed up his findings, "For I have kept from them, and am still keeping from them, that one thing which is above the power of man to make; I have kept from them the germs that float in the air, I have kept from them life."

What type of microorganisms were likely responsible for the misleading results of John Needham's experiment and were absent in Jablot's and Pasteur's experiments?

* *abiogenesis* (ah-bee″-oh-jen′-uh-sis) L. *a,* without, *bios,* life, and *genesis,* beginning.
* *biogenesis* (by-oh-jen-uh-sis) to begin with life.

hypothesis based on deduction might be the speculation that a disease such as hemophilia is an inheritable condition. This would pave the way for specific experiments that test for the influence of genetics. A nonworkable hypothesis would be that hemophilia is caused by a curse placed on the royal family of England. Because supernatural beliefs cannot be tested, they can never be subjected to the rigors of the scientific method.

With **inductive reasoning,** one applies specific observations to develop a general explanation. This method is often used in the early phases of evaluation and can formulate a generalization to be tested deductively. In the previous example, induction might begin with the observation of a family in which several people have hemophilia, and this may lead to the general idea that it is inheritable.

A lengthy process of experimentation, analysis, and testing eventually leads to conclusions that either support or refute the hypothesis. If experiments do not uphold the hypothesis—that is, if it is found to be flawed—the hypothesis or some part of it is reconsidered. This does not mean the results are invalid; it means the hypothesis may require reworking or additional tests. Eventually it is either discarded or modified to fit the results of the experiment. If the hypothesis is supported by the experiment, it is still not immediately accepted as fact. It then must be tested and retested. Indeed, this is an important guideline in the acceptance of a hypothesis. The results of the experiment must be published and repeated by other investigators.

In time, as each hypothesis is supported by a growing body of data and survives rigorous scrutiny, it moves to the next level of acceptance—the **theory.** A theory is a collection of statements, propositions, or concepts that explains or accounts for a natural event. A theory is not the result of a single experiment repeated over and over again but is an entire body of ideas that expresses or interprets many aspects of a phenomenon. When an unsupported idea is dismissed as being "just a theory," this is an incorrect use of the term as far as science is concerned. A theory is far from a weak notion or wild guess. It is a viable explanation that has stood the test of time and has yet to be disproved by serious scientific inquiries. Often theories develop and progress through decades of research and are added to and modified by new findings. At some point, evidence of the accuracy and predictability of a theory is so compelling that the next level of confidence is reached, and the theory becomes a **law,** or principle. For example, the **germ theory of disease** has been so thoroughly tested that it has clearly passed into the realm of law.

Science and its hypotheses and theories must progress along with technology. As advances in instrumentation allow new, more detailed views of living phenomena, old theories may be reexamined and altered and new ones proposed. Scientific knowledge is accumulative, and it must have built-in flexibility to accommodate new findings. It is for these reasons that scientists do not take a stance that theories are absolutely proved.

Figure 1.10 provides a summary of the scientific method in action using Edward Jenner's monumental discovery of vaccines. What is remarkable about Jenner's work is that he was the first to use scientific thought to construct a rigorous experimental model to inoculate people against disease, and he carried it through to its completion. It is also remarkable that he did this knowing nothing about viruses or even microbes. He worked out the concept of safely conferring artificial immunity long before there was any understanding of the immune system.

The Development of Medical Microbiology

Early experiments on the sources of microorganisms led to the profound realization that microbes are everywhere: Not only are air and dust full of them, but the entire surface of the earth, its waters, and all objects are inhabited by them. This discovery led to immediate applications in medicine. Thus the seeds of medical microbiology were sown in the middle to latter half of the nineteenth century with the introduction of the first practical vaccine; the germ theory of disease; and the resulting use of sterile, aseptic, and pure culture techniques.

Jenner and the Introduction of Vaccination

We saw in figure 1.10 how the English physician and scientist **Edward Jenner** modeled the scientific method. His experiments ultimately gave rise to the first viable method to control smallpox by inoculating patients with a closely related disease agent. It is often said of Jenner that his discovery saved more lives than any other in history. His work marked the beginning of an era of great scientific achievement—one that produced some of the most far-reaching developments in microbiology and medicine.

The Discovery of Spores and Sterilization

Following Pasteur's inventive work with infusions (1.1 Making Connections), it was not long before English physicist **John Tyndall** provided the initial evidence that some of the microbes in dust and air have very high heat resistance and that particularly vigorous treatment is required to destroy them. Later, the discovery and detailed description of heat-resistant bacterial endospores by **Ferdinand Cohn,** a German botanist, clarified why heat would sometimes fail to completely eliminate all microorganisms. The modern sense of the word **sterile,** meaning completely free of all infectious agents, including endospores, viruses, and prions, had its beginnings here (see chapter 11). The capacity to sterilize objects and materials is an absolutely essential part of microbiology, medicine, dentistry, and some industries.

The Development of Aseptic Techniques

From earliest history, humans experienced a vague sense that "unseen forces" or "poisonous vapors" emanating from decomposing matter could cause disease. As the study of microbiology became more scientific and the invisible was made visible, the fear of such mysterious vapors was replaced by the knowledge, and sometimes even the fear, of "germs." About 130 years ago, the first studies by **Robert Koch** clearly linked a microscopic organism with a specific disease. Since that time, microbiologists have conducted a continuous search for disease-causing agents.

At the same time that abiogenesis was being hotly debated, a few budding microbiologists began to suspect that microorganisms could cause not only spoilage and decay but also infectious diseases. It occurred to these rugged individualists that even the human body itself was a source of infection. **Dr. Oliver Wendell Holmes,** an American physician, observed that mothers who gave birth at home experienced fewer infections than did mothers who gave birth in the hospital, and the Hungarian **Dr. Ignaz Semmelweis** showed quite clearly that women became infected in the maternity ward after examinations by physicians coming directly from the autopsy room.

Observations/ information gathering

1. Dr. Jenner observed that cows had a form of pox similar to smallpox. Jenner also noted that milkmaids acquired cowpox only on the hands, and they appeared to be immune to smallpox.

Formation of Jenner's hypothesis

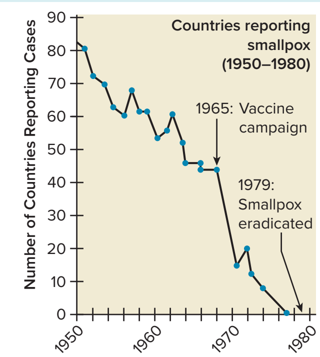
2. Jenner deduced that the cowpox was closely related to smallpox and could possibly be used on patients to provide protection similar to that of the milkmaids he had seen.

Testing the hypothesis, experiment I

3. Jenner took scrapings from cowpox blisters on the hand of a milkmaid and inoculated them into a boy who had not had smallpox. He developed minor symptoms but remained healthy.

Testing the hypothesis, experiment II

4. After a few weeks, the child was exposed twice to the pus from an active smallpox lesion. He did not acquire smallpox and appeared to have immune protection.



Reproducibility of results

5. Jenner went on to inoculate 23 other test subjects with cowpox. For the first time, he used lesions from one child to inoculate another. All subjects remained protected from smallpox.

Publishing of results; other medical testing

6. Jenner wrote a paper detailing his experiment. He called his technique *vaccination*, from the Latin *vacca* for cow. Other local English physicians began to vaccinate patients with some success.

Vaccination theory becomes widespread

7. Over the next 100 years vaccination was brought to the rest of the world through local programs. Scientists used Jenner's methods to develop vaccines for other pathogens. The theory of artificial immunity became well established.

Smallpox is eradicated from the world.

8. A massive vaccination campaign was aimed to reduce cases and to stamp out the disease completely. Billions of doses given over a decade reduced smallpox to zero. The last cases occurred in 1977, and in 1979 the disease was declared eradicated.

Figure 1.10 **Edward Jenner and the saga of the smallpox vaccine.** Jenner's work documents the first attempt based on the scientific method to control an infectious disease—smallpox. This disease was characterized by raised skin blisters called pox, and it often caused severe damage to organs. Throughout its long history this deadly disease decimated many populations worldwide, until 1977, when the last cases were reported.

The English surgeon **Joseph Lister** took notice of these observations and was the first to introduce **aseptic* techniques** aimed at reducing microbes in a medical setting and preventing wound infections. Lister's concept of asepsis was much more limited than our modern precautions. It mainly involved disinfecting the hands and the air with strong antiseptic chemicals, such as phenol, prior to surgery. It is hard for us to believe, but as recently as the late 1800s surgeons wore street clothes in the operating room and had little idea that hand washing was important. Lister's techniques and the application of heat for sterilization became the bases for microbial control by physical and chemical methods, which are still in use today.

The Discovery of Pathogens and the Germ Theory of Disease

Two ingenious founders of microbiology, **Louis Pasteur** of France **(figure 1.11)** and **Robert Koch** of Germany, introduced techniques that are still used today. Pasteur made enormous contributions to

* *aseptic* (ay-sep′-tik) Gr. *a,* no, and *sepsis,* decay or infection. These techniques are aimed at reducing pathogens and do not necessarily sterilize.

Figure 1.11 Photograph of Louis Pasteur (1822–1895), the father of microbiology. Few microbiologists can match the scope and impact of Pasteur's contributions to the science of microbiology.
Pixtal/age fotostock

our understanding of the roles of microorganisms in many aspects of medicine and industry. He developed two vaccines (rabies and anthrax) and clarified the actions of microbes in wine and beer fermentation. He invented pasteurization and completed some of the first studies showing that human diseases could arise from infection. These studies, supported by the work of other scientists, became known as the **germ theory of disease.** Pasteur's contemporary, Koch, established *Koch's postulates,* a series of proofs that verified the germ theory and could establish whether an organism was pathogenic and which disease it caused (see chapter 13). Around 1875 Koch used this experimental system to show that anthrax is caused by a bacterium called *Bacillus anthracis.* So useful were his postulates that the causative agents of 20 other diseases were discovered between 1875 and 1900, and even today they serve as a basic premise for establishing a link between pathogens and diseases. It is not an overstatement to say that Koch and his colleagues invented many of the techniques that are described in chapter 3: inoculation, isolation, media, maintenance of pure cultures, and preparation of specimens for microscopic examination. Other highlights in this era of discovery are presented in later chapters on microbial control (see chapter 11) and vaccination (see chapter 15).

Practice SECTION 1.5

10. Outline the most significant discoveries and events in microscopy, culture techniques, and other methods of handling or controlling microbes.
11. Differentiate between a hypothesis and a theory. If someone says a scientific explanation is "only a theory," what do they really mean?
12. Is the germ theory of disease actually a law, and why?
13. Why was the abandonment of the spontaneous generation theory so significant?

1.6 Taxonomy: Organizing, Classifying, and Naming Microorganisms

Learn

11. Define *taxonomy* and its supporting terms *classification, nomenclature, identification,* and *phylogenetic.*

12. Explain how the levels of a taxonomic scheme relate to each other. Give the names of the levels, and place them in a hierarchy.

13. Describe the goals of nomenclature and how the binomial system is structured. Know how to correctly write a scientific name.

Students just beginning their microbiology studies are often dismayed by the seemingly endless array of new, unusual, and sometimes confusing names for microorganisms. Learning microbial **nomenclature*** is very much like learning a new language, and occasionally its demands may be a bit overwhelming. But paying attention to proper microbial names is just like following a baseball game: You cannot tell the players apart without a program! Your understanding and appreciation of microorganisms will be greatly improved by learning a few general rules about how they are named.

The formal system for organizing, classifying, and naming living things is **taxonomy.*** This science originated more than 250 years ago when **Carl von Linné** (also known as Linnaeus; 1701–1778), a Swedish botanist, laid down the basic rules for taxonomic categories, or **taxa.** Von Linné realized early on that a system for recognizing and defining the properties of living things would prevent chaos in scientific studies by providing each organism with a unique name and an exact "slot" in which to catalog it. This classification would then serve as a means for future identification of that same organism and permit workers in many biological fields to know if they were indeed discussing the same organism. The von Linné system has served well in categorizing the 2 million or more different types of organisms that have been discovered since that time.

The primary concerns of taxonomy are classification, nomenclature, and identification, which together help to keep the tens of million of species on earth organized. Like grouping photos on your phone, many options exist to catalogue organisms, but the most useful is to group individuals together based on a common evolutionary history and shared genetic features, a so-called **phylogenetic** system. **Classification** is an orderly arrangement of organisms into groups that indicate evolutionary relationships

* *nomenclature* (noh′-men-klay″-chur) L. *nomen,* name, and *clare,* to call. A system of naming.
* *taxonomy* (tacks-on″-uh-mee) Gr. *taxis,* arrangement, and *nomos,* name.

and history. **Nomenclature** is the system of assigning names to the various taxonomic rankings of each microbial species. **Identification** is the process of using the specific characteristics and capabilities of an organism to determine its exact identity and placement in taxonomy. A survey of some general methods of identification appears in chapter 3.

The Levels of Classification

The main taxa, or groups, in a classification scheme are organized into several descending ranks called a **hierarchy.** It begins with **domain,** which is a giant, all-inclusive category based on a unique cell type, and ends with **species,*** the smallest and most specific taxon. All the members of a domain share only one or a few general characteristics, whereas members of a species share the majority of their characteristics. The order of taxa between the top and bottom levels is, in descending order: **domain, kingdom, phylum*** or **division,**[4] **class, order, family, genus,*** and **species.** Thus, each domain may be subdivided into a series of kingdoms, each kingdom is made up of several phyla, each phylum contains several classes, and so on. In some cases, additional levels can be imposed immediately above (super) or below (sub) a taxon, giving us such categories as superphylum and subclass.

To illustrate how this hierarchy works, we compare the taxonomic breakdowns of a human and a common pond protozoan **(figure 1.12).** Humans and protozoa belong to the same domain (Eukarya) but are placed in different kingdoms. To emphasize just how broad the category kingdom is, think about the fact that humans belong to the same kingdom as jellyfish. Of the several phyla within this kingdom, humans are in the Phylum Chordata, but even a phylum is rather all-inclusive, considering that humans share it with other vertebrates, as well as with creatures called sea squirts. The next level, Class Mammalia, narrows the field considerably by grouping only those vertebrates that have hair and suckle their young. Humans belong to the Order Primates, a group that also includes apes, monkeys, and lemurs. Next comes the Family Hominoidea, containing only humans and apes. The final levels are our genus, *Homo* (all races of modern and ancient humans), and our species, *sapiens* (meaning wise). Notice that for both the human and the protozoan, the categories become less inclusive and the individual members more closely related and similar in overall appearance. Other examples of classification schemes are provided in sections of chapters 4 and 5 and in several later chapters. A superior source for the taxonomic breakdown of microbes is Wikipedia. Go there to search the scientific name of any species, and its taxonomy will be shown in a box on the upper-right portion of the first page.

We need to remember that all taxonomic hierarchies are based on the judgment of scientists with certain expertise in a particular group of organisms and that not all other experts may agree with the system being used. Consequently, no taxa are permanent to any degree; they are constantly being revised and refined as new information becomes available or new viewpoints become prevalent. Our primary aim in introducing taxonomy is to present an organizational tool that helps you keep track of the various microbial groups and recognize their major categories. For the most part our emphasis will remain on the higher-level taxa (phylum, class) and genus and species.

Assigning Scientific Names

Many larger organisms are known by a common name suggested by certain dominant features. For example, a bird species may be called a yellow-bellied sapsucker, or a flowering plant, a sunflower. Some species of microorganisms (especially pathogens) are also sometimes designated by informal names, such as the gonococcus (*Neisseria gonorrhoeae*) or the TB bacillus (*Mycobacterium tuberculosis*), but this is not the usual practice. If we were to adopt common names such as the "little yellow coccus" (for *Micrococcus luteus**) or the "club-shaped diphtheria bacterium" (for *Corynebacterium diphtheriae**), the terminology would become even more cumbersome and challenging than scientific names. Even worse, common names are notorious for varying from region to region, even within the same country. A decided advantage of standardized nomenclature is that it provides a universal language that enables scientists from all countries on the earth to freely exchange information.

The **scientific name,** also known as the **specific epithet,** is assigned by using a **binomial** (two-name) **system** of nomenclature. The scientific name is always a combination of the generic (genus) name followed by the species name. The generic part of the scientific name is capitalized, and the species part begins with a lowercase letter. Both should be italicized (or underlined if italics are not available), as follows:

Histoplasma capsulatum or **Histoplasma capsulatum**

Because other taxonomic levels are not italicized and consist of only one word, one can always recognize a scientific name. An organism's scientific name is sometimes abbreviated to save space, as in *H. capsulatum,* but only if the genus name has already been stated. The source for nomenclature is usually Latin or Greek. If other languages such as English or French are used, the endings of these words are revised to have Latin endings.

An international group oversees the naming of every new organism discovered, making sure that standard procedures have been followed and that there is not already an earlier name for the organism or another organism with that same name. The inspiration for names is extremely varied and often rather imaginative. Some species have been named in honor of a microbiologist who originally discovered the microbe or who has made outstanding contributions to the field. Other names may designate a characteristic of the microbe (shape, color), a location where it was found, or a

* *species* (spee′-sheez) L. *specere,* kind. In biology, this term is always in the plural form.
* *phylum* (fy′-lum) pl. phyla (fye′-luh) Gr. *phylon,* race.

4. The term *phylum* is used for protozoa, animals, bacteria, and fungi. Division is for algae and plants.

* *genus* (jee′-nus) pl. genera (jen′-er-uh) L. birth, kind.

* *micrococcus luteus* Gr. *micros,* small, and *kokkus,* berry, and L. *luteus,* yellow.
* *corynebacterium diphtheriae* Gr. *coryne,* club, *bacterion,* little rod, and *diphtheriae,* the causative agent of the disease diphtheria.

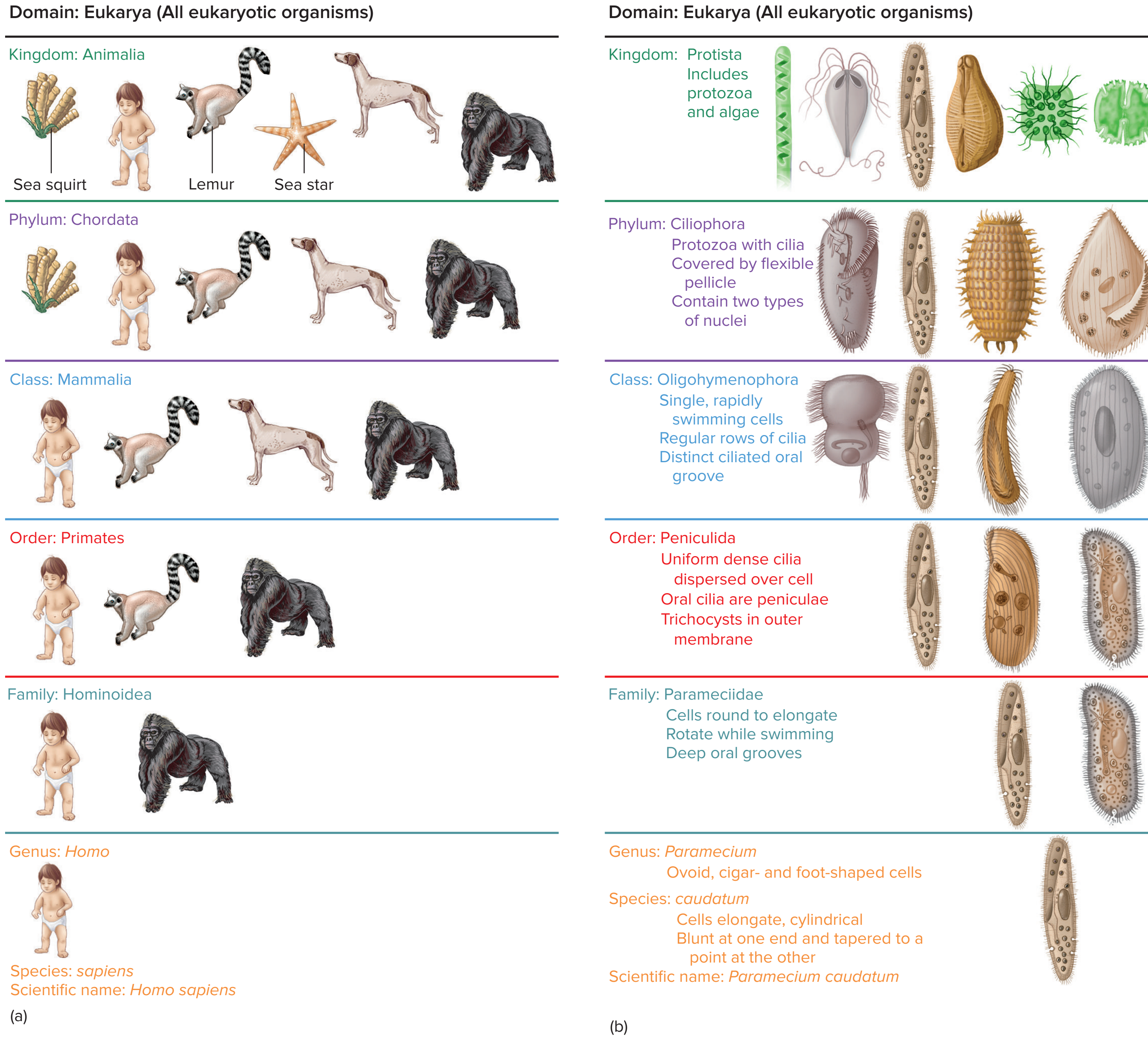
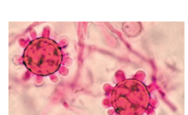
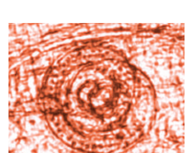


Figure 1.12 **Sample taxonomy.** Two organisms belonging to Domain Eukarya, traced through their taxonomic series. **(a)** Modern humans, *Homo sapiens.* **(b)** A common protozoan, *Paramecium caudatum.*

disease or symptom that it causes. Some examples of scientific names and origins are:

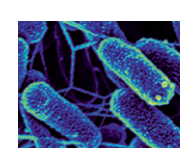


1. ***Histoplasma capsulatum*** Gr. *histo,* tissue, *plasm,* to form, and L. *capsula,* small sheath. A fungus that causes Ohio Valley fever.

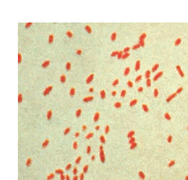


2. ***Trichinella spiralis*** Gr. *trichos,* hair, *ella,* little, and L. *spira,* coiled. The nematode worm that causes the food-borne infection trichinellosis.

1. *Source:* Dr. Libero Ajello/CDC; **2.** *Source:* CDC



3. ***Shewanella oneidensis*** Named for British bacteriologist J. M. Shewan and Lake Oneida, New York, where it was discovered. This is a remarkable species that can bioremediate radioactive metals in contaminated waste sites.



4. ***Bordetella pertussis*** After Jules Bordet, a Belgian microbiologist who discovered this bacterium, and L. *per,* severe, and *tussis,* cough. This is the cause of pertussis, or whooping cough.

3. *Source:* Rizlan Bencheikh and Bruce Arey, Environmental Molecular Sciences Laboratory, DOE Pacific Northwest National Laboratory; **4.** *Source:* CDC

When you encounter the name of a microorganism in the chapters ahead, it is helpful to take the time to sound it out one syllable at a time and repeat until it seems familiar. You are much more likely to remember the names that way—and they will become part of the new language you will be learning.

Quick Search

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

Practice SECTION 1.6

14. Differentiate between taxonomy, classification, and nomenclature.
15. What is the basis for a phylogenetic system of classification?
16. Explain the binomial system of nomenclature and give the correct order of taxa, going from most general to most specific.
17. Explain some of the benefits of using scientific names for organisms.

1.7 The Origin and Evolution of Microorganisms

Learn

14. Discuss the fundamentals of evolution, evidence used to verify evolutionary trends, and the use of evolutionary theory in the study of organisms.

15. Explain the concepts behind the organization of the two main trees of life, and indicate where the major groups of microorganisms fall on these trees.

16. Explain the bases for classification, taxonomy, and nomenclature.

17. Recall the order of taxa and the system of notation used in creating scientific names.

All Life Is Related and Connected Through Evolution

As we indicated earlier, *taxonomy,* the classification of biological species, is a system used to organize all of the forms of life. In biology today, there are different methods for deciding on taxonomic categories, but they all rely on the history and relatedness of organisms. The natural relatedness between groups of living things is called their **phylogeny.** Biologists can apply their knowledge of phylogenetic relationships to develop a system of taxonomy.

To understand how organisms originate, we must understand some fundamentals of **evolution.** You have no doubt heard comments that dismiss evolution as "only a theory" as though there remain significant problems with its acceptance. But you have also learned that a scientific theory is a highly documented and well-established concept. The body of knowledge that has accumulated over hundreds of years regarding the process of evolution is so significant that scientists from all disciplines consider evolution to be a fact. It is an important theme that underlies all of biology, including microbiology. Put simply, the scientific principle of evolution states that living things change gradually over time. The process of evolution is selective: Those changes that most favor the survival of a particular organism or group of organisms tend to be retained, and those that are less beneficial to survival tend to be lost. The great naturalist Charles Darwin labeled this process natural selection. We do not have the space here to present a detailed analysis of evolutionary theories, but the occurrence of evolution is supported by a tremendous amount of evidence from the fossil record and from the study of **morphology** (structure), **physiology** (function), and **genetics** (inheritance). Evolution accounts for the millions of different species on the earth and their adaptation to its many and diverse habitats.

Evolution is founded on two premises: (1) that all new species originate from preexisting species through inheritance of traits and (2) that closely related organisms have similar features because they evolved from common ancestral forms. Usually evolution progresses toward greater complexity, and evolutionary stages range from simple, less evolved forms that are close to an ancestral organism to more complex, evolved forms that have advanced beyond the ancestral forms. Regardless of their evolutionary history, all species presently residing on the earth are modern, but some have arisen more recently in evolutionary history than others.

Traditionally we present the history of life, or phylogeny, in the form of branching trees that are designed to show the origins of various life forms (**figures 1.13** and **1.14**). At the base are the oldest ancestral forms (somewhat like roots), and the trunk indicates the progression of major lines that emerge through selection. Branches split off the main trunk as further selection and modification occur. With this arrangement, more closely related organisms appear nearer to each other on the tree. Any tree of life is nothing more than a system for classifying organisms, and the characteristics used for the process are specified by the person or group creating the tree. Classifying organisms alphabetically (aardvark, acinetobacter, aloe, antelope) or by size (giant redwood, blue whale . . .) are equally valid strategies. However, the most scientifically useful classification schemes group organisms according to their biological characteristics, using the tree to display the evolutionary relationships between organisms.

Systems for Presenting a Universal Tree of Life

The earliest classification schemes assigned every living thing to either the Plant Kingdom or the Animal Kingdom, even though many organisms were a poor fit for either. As knowledge grew concerning cellular structure, means of acquiring nutrients, and how organisms moved about, Robert Whittaker developed a five-kingdom system (figure 1.13) in the 1960s that remained the standard for many years. Individual members of the five kingdoms—the **monera, fungi, protists, plants,** and **animals**—were easily distinguished from one another using techniques common to most laboratories during the mid-twentieth century.

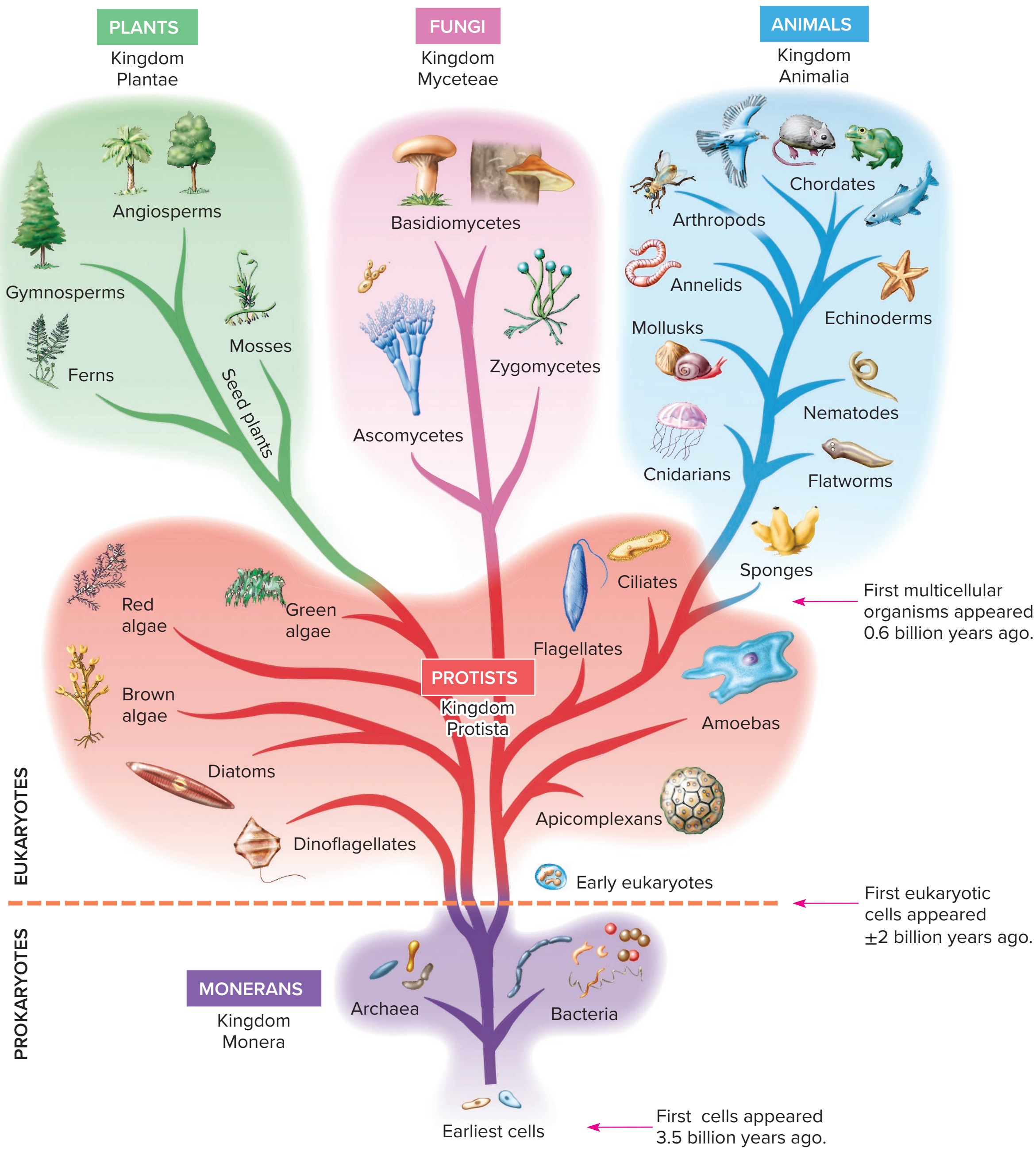


Figure 1.13 **Traditional Whittaker system of classification.** In this system, kingdoms are based on cell structure and type, the nature of body organization, and nutritional type. Bacteria and Archaea (monerans) have prokaryotic cells and are unicellular. Protists have eukaryotic cells and are simple unicellular and colonial organisms. They can be photosynthetic (algae), or they can feed on other organisms (protozoa). Fungi are eukaryotic cells with unicellular or multicellular bodies; they have cell walls and are not photosynthetic. Plants have eukaryotic cells, are multicellular, have cell walls, and are photosynthetic. Animals have eukaryotic cells, are multicellular, do not have cell walls, and derive nutrients from other organisms.

By the late twentieth century, the manner in which organisms were studied was undergoing a dramatic change. The techniques of molecular biology allowed scientists to examine the structure and function of individual genes and to clarify the relationships between organisms based on similarities in their genetic material, rather than simply shared characteristics. Using these new molecular methods, Carl Woese and George Fox proposed a classification system that some have likened to a shrub of life rather than a tree (figure 1.14). In this system, organisms are most broadly classified as belonging to one of three domains. The members of the **Domain Bacteria** have prokaryotic cells and are what most people think of as traditional bacterial species. The **Domain Eukarya** contains all of the organisms that display a eukaryotic cell structure and includes the Kingdom Protista, Kingdom Fungi, Kingdom Plantae, and Kingdom Animalia. Members of the **Domain Archaea** also possess prokaryotic cells, but these cells are so distinct from those