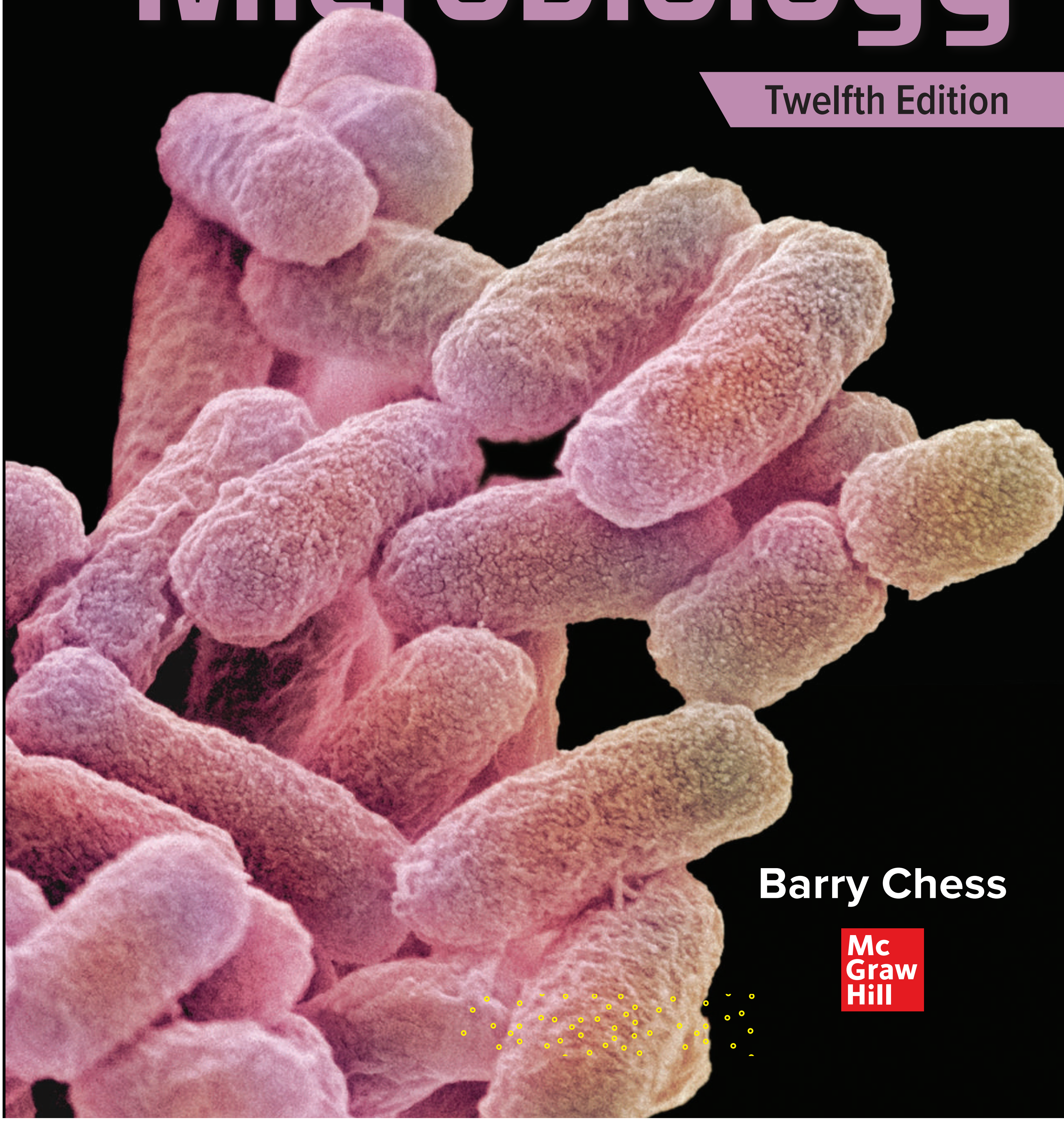
Talaro's Foundations in Microbiology

Twelfth Edition



Barry Chess

McGraw Hill

TALARO'S FOUNDATIONS IN MICROBIOLOGY, TWELFTH EDITION

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Brief Contents

About the Author

Barry Chess has taught microbiology at Pasadena City College (PCC) 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 skiing, diving, or hiking with Toby, his 110-pound pandemic puppy. 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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Steve Gschmeissner/Science Photo Library/Getty Images

The twelfth edition of *Foundations in Microbiology* was written entirely under the cloud of SARS-CoV-2, the greatest example of the continuing relevance of microbiology in every aspect of our lives. Go away.

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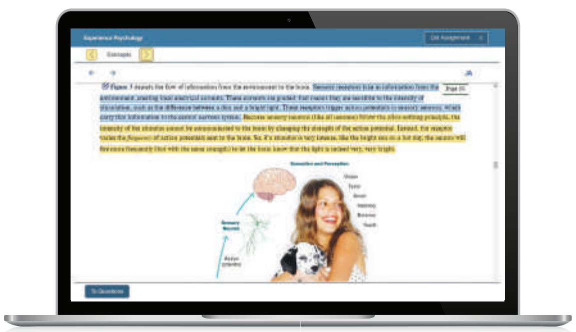

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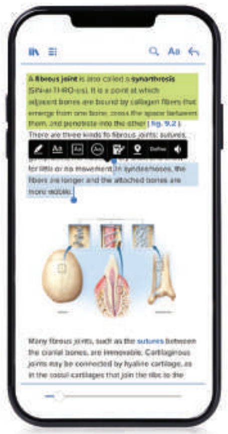

"I really liked this app—it made it easy to study when you don't have your text-book in front of you."

- Jordan Cunningham,
Eastern Washington University

iPhone: Getty Images

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With the help of our Relevancy Modules within McGraw Hill Connect, students can see how microbiology actually relates to their everyday lives. For select microbiology titles, students and instructors can access the Relevancy Modules eBook at no additional cost. Auto-graded assessment questions which correlate to the modules are also available within Connect. Each module consists of videos, an overview of basic scientific concepts, and then a closer look at the application of these concepts to the relevant topic. Some topics include microbes and cancer, fermentation, vaccines, biotechnology, global health, SARS-CoV-2, antibiotic resistance, the microbiome, and immunology.

Virtual Labs and Lab Simulations

While the biological sciences are hands-on disciplines, instructors are often asked to deliver some of their lab components online: as full online replacements, supplements to prepare for in-person labs, or make-up labs.

These simulations help each student learn the practical and conceptual skills needed, then check for understanding and provide feedback. With adaptive pre-lab and post-lab assessment available, instructors can customize each assignment.

From the instructor's perspective, these simulations may be used in the lecture environment to help students visualize complex scientific processes, such as DNA technology or Gram staining, while at the same time providing a valuable connection between the lecture and lab environments.

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In consultation with the Online Learning Consortium (OLC) and our certified Faculty Consultants, McGraw Hill has created preconfigured courseware using OLC's quality scorecard to align with best practices in online course delivery. This turnkey courseware contains a combination of formative assessments, summative assessments, homework, and application activities, and can easily be customized to meet an individual's needs and course outcomes.

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Tegrity in Connect is a tool that makes class time available 24/7 by automatically capturing every lecture. With a simple oneclick start-and-stop process, you capture all computer screens and corresponding audio in a format that is easy to search, frame by frame. Students can replay any part of any class with easy-to-use, browser-based viewing on a PC, Mac, iPod, or other mobile device.

Educators know that the more students can see, hear, and experience class resources, the better they learn. In fact, studies prove it. Tegrity's unique search feature helps students efficiently find what they need, when they need it, across an entire semester of class recordings. Help turn your students' study time into learning moments immediately supported by your lecture. With Tegrity, you also increase intent listening and class participation by easing students' concerns about note-taking. Using Tegrity in Connect will make it more likely you will see students' faces, not the tops of their heads.

Test Builder in Connect

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- add instructions and configure default settings.

Test Builder provides a secure interface for better protection of content and allows for just-in-time updates to flow directly into assessments.

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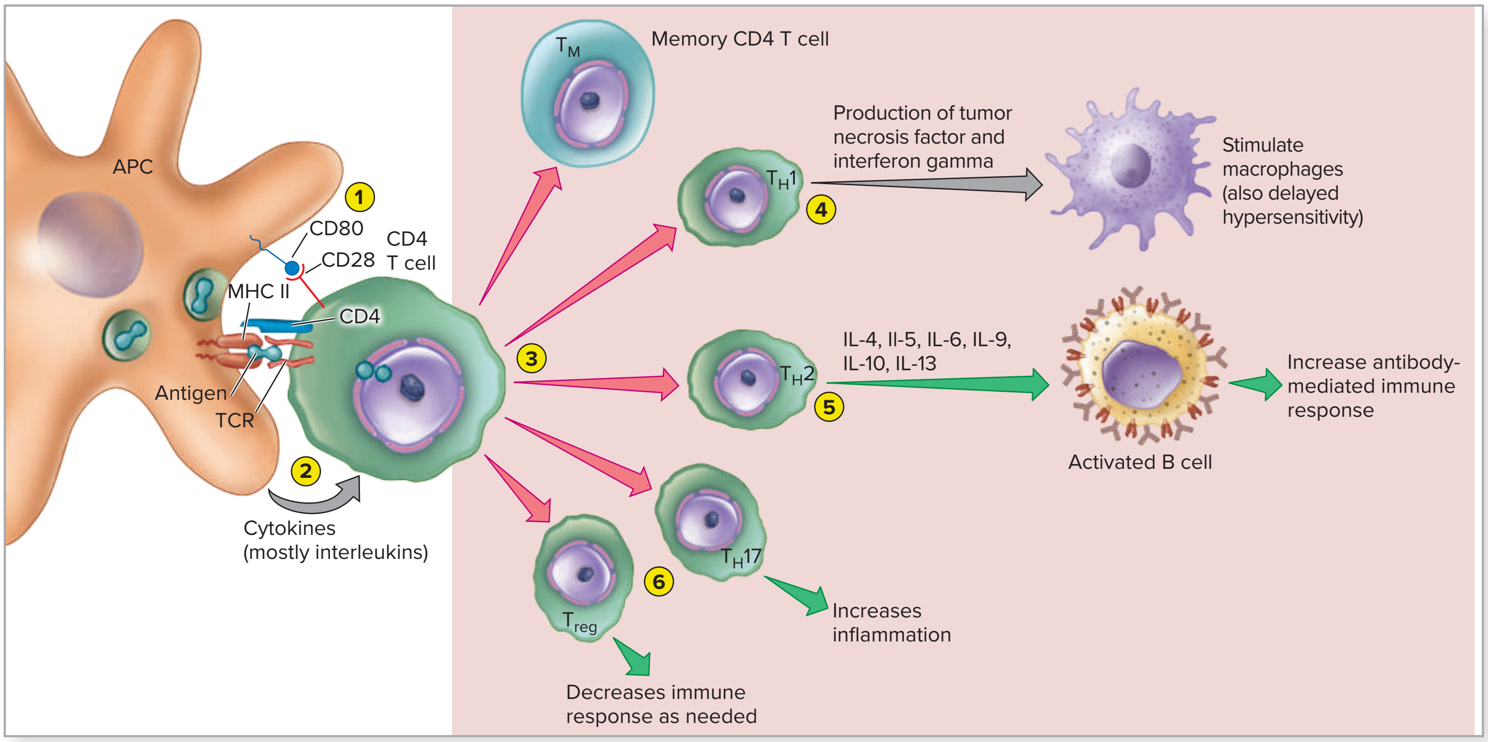
Designed for Today's Students

Art and organization of content make this book unique

Instagram, TikTok, and Snapchat can teach you a thing or two. Maybe not much about microbiology, but certainly something about how to merge words and images to communicate effectively. I have no illusions about this book going viral, but if the occasional student walks away thinking that a concept was interesting, easy to understand, even funny, we'll call that a win. Crafting such a learning tool 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 twelfth edition, the author has gone through the book page by page, sentence by sentence, to make sure it continues to meet its goals of explaining complex topics clearly and vividly and to present material in an engaging manner that aids in understanding. Art has been placed where it makes the most sense in the flow of the narrative, figures break down complex processes into their component parts, and explanations are clear, concise, and correctly targeted to the reader. 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—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. Photos, 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** A Viral Pandemic

The origin of the **virus** will never be known for certain, and the first person in the United States to contract the disease is likely also lost to history. In the United States, cases first appeared in the Pacific Northwest, and the speed of the outbreak during March and April quickly outpaced early efforts to protect against the virus.

George Parrish, the health officer for Portland, Oregon, began a campaign to educate the public as to how the virus was transmitted, emphasizing the need to control **coughing and sneezing**, especially in crowded public places. He reached out to local religious leaders to help deliver the message from the pulpit to their congregations. A week after the first confirmed case in the city, the Oregon State Board of Health ordered the **shutdown** of all public gathering places; no restaurants, no theaters, and no school for tens of thousands of students. Officials reminded the public of the importance of **hand washing** and began a campaign to encourage **social distancing**. Two hundred miles to the north, Seattle had already seen a dozen deaths from the disease. The mayor asked that people avoid gathering in churches, and some public gatherings were banned entirely. On the opposite coast, the situation was no better as the White House, Congress, and the Supreme Court were closed to the public. When **masks** were found to reduce the risk of viral **transmission**, government agencies publicized their usefulness. The *San Francisco Chronicle* printed a public service announcement calling those who refused to wear masks "dangerous slackers" and emphasizing that beyond keeping oneself healthy, wearing a mask protected others who were more likely to suffer serious consequences. Shortly thereafter, the city of San social distancing recommendations. Across the country, politics intruded as people began to choose sides. In Portland, a city council debate became chaotic when one member decried a masking order as "autocratic and unconstitutional," adding that "under no circumstances will I be muzzled like a [rabid] dog." In San Francisco, 2,000 people gathered indoors to join an anti-mask rally, which included physicians, as well as one member of the Board of Supervisors. Public outcry grew louder when several city officials, including the mayor, were photographed attending a boxing match without masks. The situation in San Francisco came to a head when a special officer for the Board of Health shot a man in a dispute over mask-wearing (he survived but was arrested for not following the officer's orders).

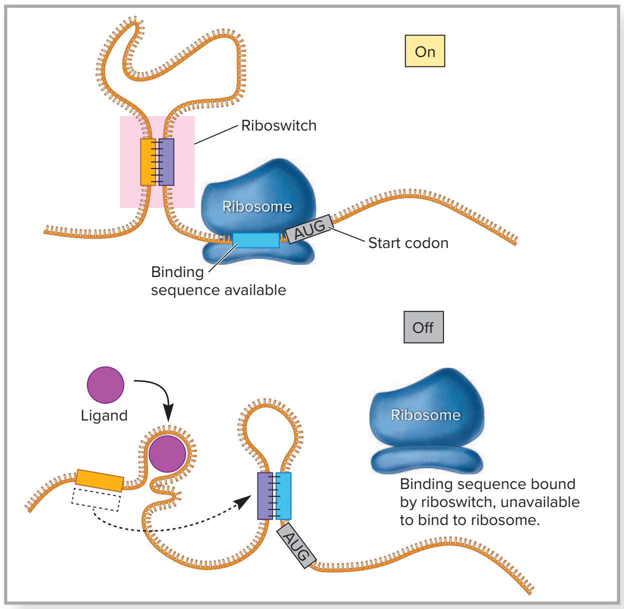
Because most **public health** decisions were made at the local level, the success of mitigation strategies varied wildly. Health officials in Philadelphia advised the mayor to cancel several large public gatherings, including a parade, to prevent the spread of the virus. The mayor refused, and a surge in cases followed. Meanwhile, in St. Louis, similar gatherings were quickly shut down, robbing the virus of an opportunity to spread. In the end, St. Louis had one-eighth as many deaths as did Philadelphia. While most medical experts recommended **quarantines** and face masks, health officials in many cities, according to the *New York Times,* "opposed both these measures and placed great reliance on [the development of a] **vaccine**."

Cynthia Goldsmith/Centers for Disease Control and Prevention; (background) Digital Mammoth/Shutterstock

Illustrated to Increase Understanding

The author's experience and talent transform difficult concepts

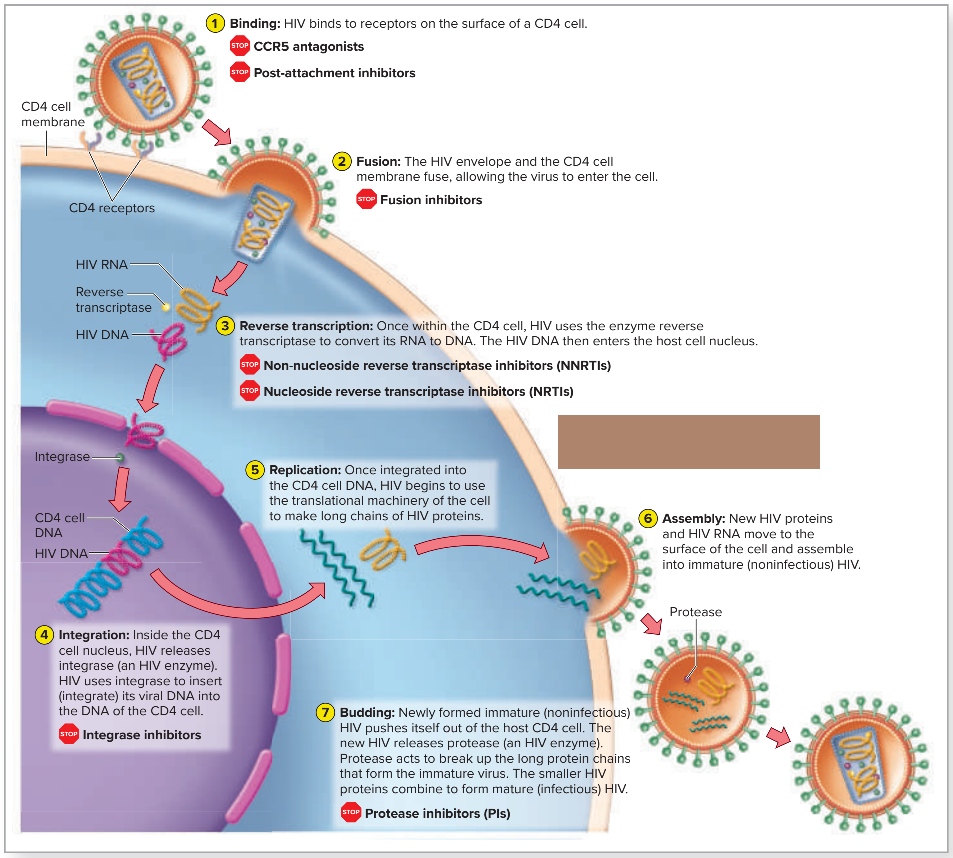
Truly instructional artwork has always been a hallmark feature of *Foundations in Microbiology,* and the twelfth edition of the book continues to set the standard. Common sense, backed by many decades of research, has shown that when abstract concepts are explained using scientifically accurate illustrations,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



Barry Chess/McGraw Hill

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.



Source: AIDS info, U.S. Department of Health and Human Services

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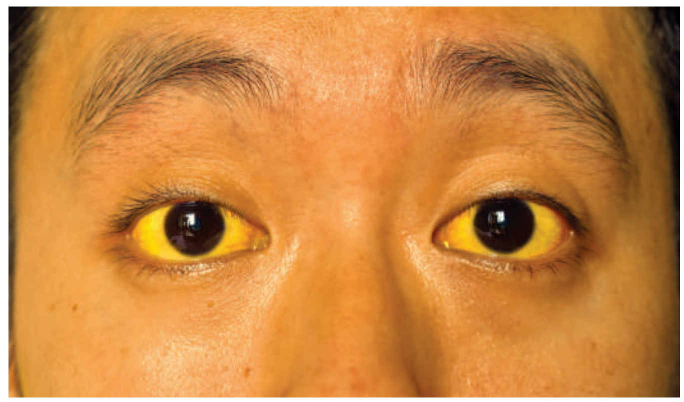
Designed for the Twenty-First Century

Clinical photos help students visualize

A picture is worth a thousand words. And significantly more than a thousand when the words are bullious, maculopapular, and petechiae. Students in the microbiology classroom are constantly being asked to evaluate things they've never seen before, using a vocabulary that is both brand new and extraordinarily specific in most instances. Hardly seems fair. To that end, *Foundations in Microbiology* has clinical photos–lots of clinical photos–because the best way to learn the difference between chicken pox and measles is to see the difference between chickenpox and measles. Additionally, wherever possible, medical conditions are shown on a variety of skin tones because, well, people come in a variety of skin tones.

JaroslavMoravcik/Shutterstock



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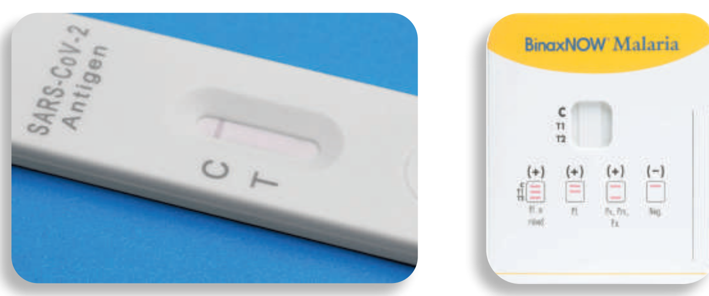
Modern Processes

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



(a) (b)

Figure 17.17 **Rapid diagnostic tests. (a)** A SARS-CoV-2 (COVID-19) rapid antigen test. This test detects viral antigens in a saliva sample. The C line is a control and shows that the test is functioning correctly. The lack of a line in the T (test) portion of the window indicates that the sample does not contain antigens from the virus. **(b)** A rapid diagnostic panel that identifies antigens from different species of *Plasmodium,* the agent of malaria, using a small drop of whole blood.

(a): staukestock/Shutterstock; (b): Courtesy of Alere, Inc.

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.

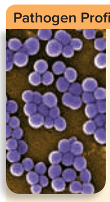
Practice SECTION 13.1

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. 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).

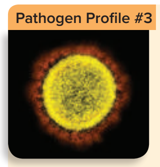
Primary Infections/Disease Local cutaneous infections include folliculitis, furuncles, and carbuncles, as well as bullous impetigo. Systemic infections include osteomyelitis, pneumonia, and endocarditis. A rare cause of meningitis. Diseases due to *S. aureus* toxins include food intoxication, scalded 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. Widespread drug resistance 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 #3 *SARS-CoV-2*



American Photo Archive/Alamy Stock Photo

Microscopic Morphology Spherical virus with a crownlike appearance due to the projection of spikes from the viral envelope.

Identified By Detection of viral antigens using antibody-based assays provides rapid testing capability, but the test is dependent on a high viral load and is most accurate when used on symptomatic persons. Nucleic acid amplification tests, primarily RT-PCR, provide high specificity and sensitivity throughout the course of infection, but turnaround time can be 24 hours or more. Nasopharyngeal swabs are the normal source of sample for testing.

Habitat The virus is widespread in humans and animals, with bats the likely natural reservoir. SARS-CoV-2 is spread by respiratory droplets, with some possibility of aerosol spread.

Virulence Factors Ability to induce systemic inflammation. Rapid mutation in spike proteins results in multiple viral strains with differing degrees of infectivity, virulence, and ability to evade vaccine-induced immunity.

Primary Infections/Disease SARS-CoV-2 infection leads to COVID-19 (**Co**rona**vi**rus **d**isease, 20**19**). The pathological effects are dependent on systemic inflammation, causing damage to the kidney, heart, liver, and respiratory system. About 70% of deaths are due to acute respiratory distress syndrome, with the remainder attributed to organ damage. Most deaths occur in the elderly or those with co-morbidities. Complications include long COVID, in which symptoms may continue for many months, and multisystem inflammatory syndrome in children and adults (MIS-C, MIS-A), in which severe systemic inflammation may occur several weeks after resolution of the initial infection.

Control and Treatment Control relies on inhibiting the spread of the virus through frequent testing, isolation, social distancing, and masking. Vaccination provides protection against severe disease and reduces viral spread in the population. Three vaccines are approved for use in the United States, one based on a replication-incompetent adenovirus carrying genetic material from the virus (Johnson & Johnson) and two mRNA vaccines containing mRNA coding for a portion of a viral spike (Moderna and Pfizer). Treatment relies on supporting respiration as needed, treating secondary respiratory infections, and reducing inflammation of the tissues. Treatment includes administration of antiviral drugs (remdesivir, Paxlovid, molnupiravir) along with immunomodulators (dexamethasone, baricitinib). Monoclonal antibody treatments (tocilizumab, sotrovimab) targeted against the virus or modulators of immunity may be helpful, and serum from convalescent individuals may be used in patients who are immunocompromised.

System Profile

System	Skin/Skeletal	Nervous/Muscle	Cardiovascular/ Lymphatic/Systemic	Gastrointestinal	Respiratory	Urogenital
Disease		Fatigue, lethargy, myalgia	Organ failure (heart, kidney, liver)		Acute respiratory distress syndrome	

Pedagogy created to promote active learning

Making Connections

If a textbook provides the facts behind the story, then Making Connections provides the story behind the facts. In the twelfth edition, new Making Connections features have been used to bring an enhanced degree of diversity, inclusion, and equity to the study of microbiology, highlighting the contributions of people often overlooked.

1.2 MAKING CONNECTIONS

A More Inclusive WHO

Most of us are well acquainted with the derogatory names associated with SARS-CoV-2; China flu, Chinese virus, Kung flu, some even worse. We're also familiar with racist acts—from rudeness to murder—committed by people who thought their actions were somehow justified based on the origins of the virus. But a debate over the naming of SARS-CoV-2 tells only a part of the story.

The general rule on naming an organism is that if you discovered it, you get to name it. But because the World Health Organization generally takes the flak when a name proves offensive, the WHO has always had a hand in the name game. For more than a century most new organisms were named after people, places, and animals, giving us *Salmonella* (after David Salmon), Marburg virus (a city in Germany), and swine (pig) flu. Unfortunately, this strategy also gave us GRID (gay-related immune deficiency) an early name for AIDS. Did the name Norwalk virus reduce property values in Norwalk, Ohio? Did hog farmers lose money when swine flu was named? The answer to both questions is almost certainly yes.

In 2015, the WHO released updated guidance for the naming of newly discovered pathogens that affect humans. People, places, and animals were out, as were occupations, food, and terms that incite fear, like fatal or epidemic. The new rules relied on symptoms (respiratory disease, diarrhea) along with epidemiological terms (seasonal, severe, juvenile). Hence, severe acute respiratory syndrome associated coronavirus type 2, or SARS-CoV-2. The WHO, by the way, does not advocate renaming pathogens or diseases with names already established in the literature. Ebola virus and Chagas disease are here to stay.

While certainly more respectful of people's feelings, there are many microbiologists who feel that the new rules produce names lacking poetry; that Rocky Mountain spotted fever is just an inherently more interesting name than maculopapular rash disease, type 11 (or something similar). Others, like Columbia University virologist Ian Lipkin, feel that the new name recommendations obscure relevant facts, saying "I don't see how it will be helpful to eliminate names like monkey pox, that provide insights into natural hosts and potential sources of infection." And sometimes the best of intentions just don't work out. SARS, a name designed not to offend, did not go over well in Hong Kong, which is officially known as the Hong Kong special administrative region, or SAR.

Delta Airlines likely lost money due to a particularly virulent strain of SARS-CoV-2 being named the delta variant (after Delta, the fourth letter of the Greek alphabet). Should the airline have any recourse to recover lost money from the U.S. government or World Health Organization? (Recall that the U.S. government distributed billions of dollars to businesses that were hurt by the pandemic.)

3.2 MAKING CONNECTIONS

Frau Hesse's Medium

Bacteria have a history of being nearly impossible to separate from one another for individual study. As far back as 1763, Carl Linnaeus, in an act of surrender, classified all bacteria as belonging to the taxonomic order *Chaos*. Skip ahead a century and microbiologists like Robert Koch began to realize that if he could grow bacteria on a solid medium—as when mold grows on bread or cheese—isolated colonies would form that could be more easily studied.

Walther Hesse was a laboratory technician in Koch's lab and was tasked with creating a solid bacterial growth medium. His efforts focused on using gelatin to congeal the beef stock used in the lab. While this produced an acceptably solid surface when cold, at the warmer temperatures needed to grow bacteria, the medium quickly melted. Making matters worse, some bacteria would use the gelatin as a food source, digesting it and liquefying the medium. The beef broth used to grow bacteria in the laboratory was prepared by Walter Hesse's wife, Angelina Fanny Hesse, who occasionally worked as an assistant and scientific illustrator for the lab. She suggested the use of agar, a polysaccharide derived from algae, which was commonly used to thicken a number of foods (especially desserts) in Asia, and Angelina learned of it through friends of hers who had lived in Indonesia. Once boiled, broth containing agar cooled to produce a firm surface ideal for isolating bacterial growth. What's more—unlike gelatin—agar was not digestible by bacteria, solving yet another problem.

In an 1882 paper identifying the causative agent of tuberculosis, Robert Koch extolled the virtues of agar, "The tubercule bacilli can also be cultivated on other media . . . they grow, for example, on a gelatinous mass which was prepared with agar-agar, which remains solid at blood temperature, and which has received a supplement of meat broth and peptone." Later papers allude to "Koch's plate technique" or the ubiquitous "Petri dish," but Angelina Hesse's name was never attached to her discovery. In a 1939 paper reviewing the transformative effect that the introduction of agar-based medium had on the science of microbiology, Arthur Hitchens and Morris Leikind, two scientists from the Walter Reed Medical Center and Johns Hopkins University, proposed a suggestion, "Could not 'plain agar' from now on be designated as 'Frau Hesse's medium'? Her contribution to bacteriology makes her immortal."

U.S. National Library of Medicine

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

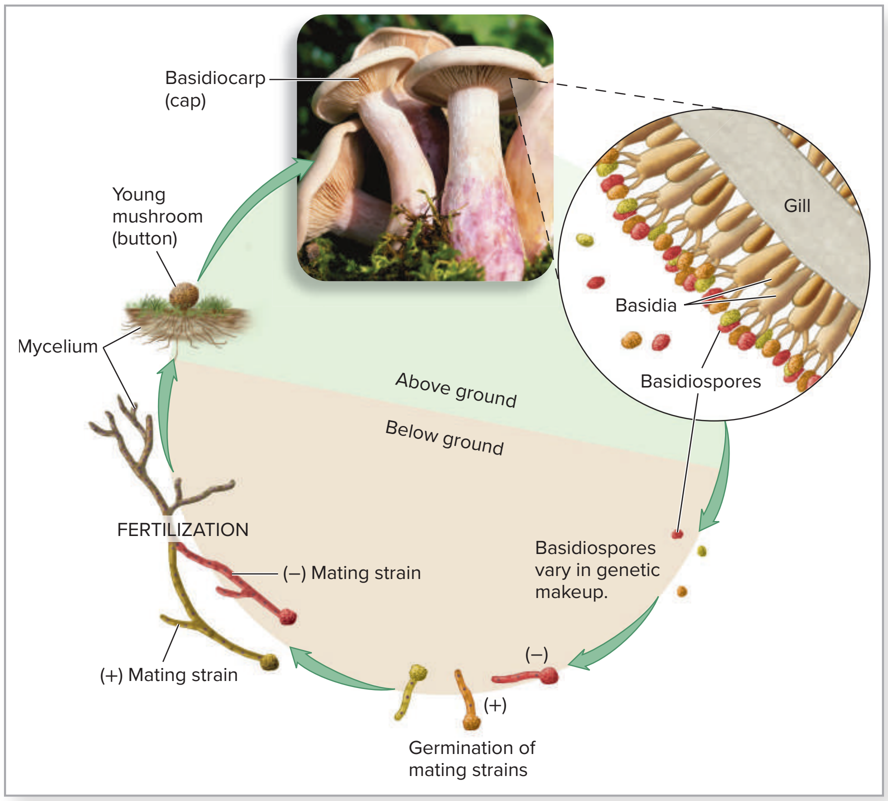
Footnotes provide the reader with additional information about the text content.

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

Creating Lifelong Learners

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.



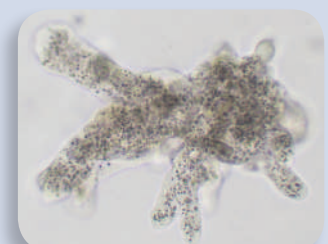
IT Stock/age fotostock

Illustrated Tables

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

I. Microscopes using visible light illumination
Maximum effective magnification = 1,000× to 2,000×*.
Maximum resolution = 0.2 µm.

The subject here is amoeba examined at 400× with four types of microscopes. Notice the differences in the appearance of the field and the degree of detail shown using each type of microscope.

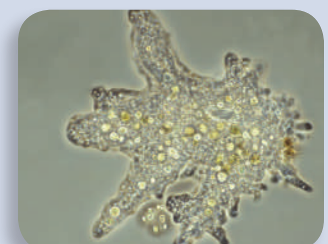


Bright-field microscope

Common multipurpose microscope for live and preserved stained specimens; specimen is dark, field is bright; provides fair cellular detail.

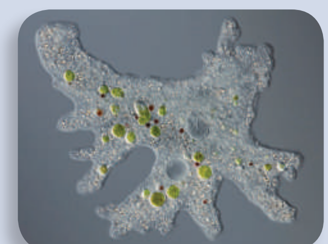
Dark-field microscope

Best for observing live, unstained specimens; specimen is bright, field is dark; provides outline of specimen with reduced internal cellular detail.



Phase-contrast microscope

Used for live specimens; specimen is contrasted against gray background; excellent for internal cellular detail.



Differential interference contrast microscope

Provides very detailed, highly contrasting, three-dimensional images of live specimens.

(bright-field): Lisa Burgess/McGraw Hill; (dark-field): Lisa Burgess/McGraw Hill; (Phase-contrast): Stephen Durr; (Differential interference): Micro photo/iStock/Getty Images

Clinic Cases

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

Mary Had a Little Lamb. I'd Like Some of Her Cells

Over a period of a few weeks, five patients with similar complaints were seen by doctors in the New York area. All five presented with fever, fatigue, chills, and headache, a combination of signs and symptoms so general that they provide little diagnostic information. Three of the five reported preexisting medical conditions, including one patient with atrial fibrillation and kidney stones, one with Parkinson's disease and osteoarthritis, and one with multiple sclerosis. Digging deeper, doctors discovered that all five patients had recently traveled to Germany to receive injections of processed cells from sheep fetuses, a treatment known as live cell therapy. Despite a complete lack of clinical evidence since being introduced in the 1930s, the procedure is commonly advertised as having anti-aging effects and as a treatment for a variety of ailments, including those displayed by the three patients reporting preexisting conditions.

A call to German health authorities revealed that they were investigating an outbreak of human Q fever associated with inhalation exposure to a flock of sheep. The flock was used to produce fetal sheep cell injections by the German physician who treated the five patients. Although live cell therapy is prohibited in the United States, it is less tightly regulated in other countries. In Germany, for instance, the procedure is permitted if the cells are prepared by a doctor for use only in his or her own patients.

Immunofluorescence testing revealed *Coxiella burnetii*–specific antibodies in all five patients, with especially high IgM titers, suggesting acute infection. The patients were successfully treated with doxycycline, although three patients reported lingering symptoms of the disease (fatigue, chills, sweats, and difficulty sleeping) up to 10 months after exposure.

Q fever is a zoonotic disease. How do the patients in this case differ from those who would normally be at risk of contracting the disease?

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 Dr. 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*?" Dr. 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 twelfth 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.

Case Study Analysis

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

Case Study Analysis

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

On the Test

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

On the Test

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

1. The nurse in an emergency department is reviewing discharge instructions with a client. The client asks for clarification of a zoonosis with regard to the type of illness. What is the **best** response by the nurse?
   a. A zoonosis refers to any viral disease.
   b. A zoonosis is any disease that can be successfully treated with antibiotics.

Writing Challenge

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

Writing Challenge

For each question, compose a one- or two-paragraph answer that includes the 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

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.

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Organized to Promote Critical Thinking

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

Concept Mapping

Concept Mapping activities have been designed for each chapter, and an introduction to concept mapping can be found on Connect.

Concept Mapping

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

Critical Thinking

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

Critical Thinking

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

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

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

Visual Assessment

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

Visual Assessment

1. Identification of a unique skin rash can often be the first step in diagnosing a disease. What infectious agents are indicated by the rashes below?

enuengneng/Shutterstock

James Gathany/CDC

Changes to *Foundations in Microbiology, Twelfth Edition*

Global Changes to the Twelfth Edition

- Thousands of changes were made to this edition, most of which you'd never notice. Sentences were clarified, statistics were updated, figure legends were changed. All in the name of making this edition a little bit better than the last. The following list represents a few of the larger changes you'll encounter.
- **Diversity, Equity, and Inclusion:** McGraw Hill is dedicated to creating products that foster a culture of belonging and are accessible to all the diverse global customers we serve. Within this edition, content has been reviewed to implement inclusive content guidelines around topics including generalizations and stereotypes, gender, abilities/disabilities, race/ethnicity, sexual orientation, diversity of names, and age.
- **Art Accessibility:** Accessibility has been improved in this edition by ensuring meaningful text and images are distinguishable and perceivable by users with limited color vision and moderately low vision.

Chapter-Specific Changes

Chapter 1

- New Case Study examines the similarities between the 1919 Spanish influenza pandemic and the COVID-19 pandemic.
- New discussion of the slave Onesimus and variolation, his contribution to protecting the inhabitants of Boston from smallpox in 1721.
- Making Connections: *A More Inclusive WHO* discusses the latest naming standards established by the World Health Organization to promote equity and inclusion.
- Thirteen new photos and illustrations.

Chapter 2

- New information on the use of liposomes to deliver mRNA in the SARS-CoV-2 vaccine.

Chapter 3

- Clarified discussion of microscopy, particularly magnification and resolution.
- Making Connections: *Frau Hesse's Medium* examines Angelina Hesse's use of agar to prepare microbiological media.
- Twenty new photos and illustrations.

Chapter 4

- The discussion of bacterial membrane structure has been clarified.
- Updated and clarified explanation of prokaryotic classification as well as the upper and lower limits of bacterial size.
- Eleven new photos and illustrations.

Chapter 5

- A new discussion of endosymbiotic theory opens the chapter.
- Nineteen new photos and illustrations.

Chapter 6

- The chapter opens with a new introduction to viruses.
- Seven new photos and illustrations.

Chapter 7

- An updated and expanded discussion of human microbiota is now found in the chapter.

Chapter 8

- Three new photos and illustrations.

Chapter 9

- A short discussion of RNA and its contribution to the expression of genes throughout the cell has been added.
- Twenty-four new photos and illustrations.

Chapter 10

- The explanation of recombinant DNA technology has been clarified.
- A discussion of Onpattro, the first RNAi therapy approved for use, has been added to the chapter.
- Nineteen new photos and illustrations.

Chapter 11

- A discussion of the use of ultraviolet disinfection during the COVID-19 pandemic has been added.
- New information on the use of phenol and hydrogen peroxide has been added.
- Seven new photos and illustrations.

Chapter 12

- Updated discussion of pre-exposure prophylaxis for HIV.
- A new section focusing on the treatment of COVID-19.
- Five new photos and illustrations.

Chapter 13

- New Case Study on coronavirus infection in zoo animals and sylvatic cycles.
- New Clinical Connection examining exactly when humans begin to acquire resident microbiota.
- Twelve new photos and illustrations.

Chapter 14

- New discussion on the role of erythrocytes and neutrophil extracellular traps in the immune system.
- Five new photos and illustrations.

Chapter 15

- New Case Study on the development of vaccines against SARS-CoV-2.
- New Clinic Case on the use of monoclonal antibodies in the treatment of COVID-19.
- New discussion of viral vector and RNA vaccines.
- Seventeen new photos and illustrations.

Chapter 16

- Four new photos and illustrations.

Chapter 17

- A new discussion of MALDI-TOF (Matrix-Associated Laser Desorption/Ionization Time of Flight) as a means of identifying microbial samples.
- A new discussion of point-of-care and rapid diagnostic tests.
- Seventeen new photos and illustrations.

Chapter 18

- A new discussion of necrotizing fasciitis.
- Seventeen new photos and illustrations.

Chapter 19

- A new Clinic Case on fecal microbiota transplantation.
- Seventeen new photos and illustrations.

Chapter 20

- A new Clinic Case concerning an outbreak of *Burkholderia pseudomallei,* a Tier 1 Select Agent.
- An updated discussion of the genus *Haemophilus*.
- Fifteen new photos and illustrations.

Chapter 21

- A new Case Study on COVID-19 and endemic typhus.
- An expanded discussion of *Vibrio vulnificus and Vibrio parahaemolyticus*.
- New Pathogen Profile focused on *Vibrio vulnificus* and *Vibrio parahaemolyticus*.
- Updated discussion of *Bartonella.*
- A new Clinic Case concerning live cell therapy.
- Eighteen new photos and illustrations.

Chapter 22

- A new Case Study concerning coccidioidomycosis.
- New discussion concerning increasing numbers of *Candida auris* infections being encountered.

- A new Clinic Case concerning mucormycosis infections in patients diagnosed with COVID-19.
- Fifteen new photos and illustrations.

Chapter 23

- Ten new photos and illustrations.

Chapter 24

- Eleven new photos and illustrations.

Chapter 25

- A new Case Study on a SARS-CoV-2 outbreak connected to a wedding in a small town.
- A new section on Coronavirus has been added.
- A new Pathogen Profile concerning coronavirus has been added.
- Discussion of a universal influenza vaccine has been added.
- A new Making Connections feature recounts the initial use of wild animal vaccination against rabies, using chicken heads as bait.
- The discussion of HIV has been updated to reflect the changing epidemiology and pathogenesis of the disease.
- The discussion of polio has been updated and condensed.
- Twenty-two new photos and illustrations.

Chapter 26

- New Case Study focused on the death of eagles from ingestion of novel toxin produced in cyanobacteria.
- Four new photos and illustrations.

Chapter 27

- Five new photographs and illustrations.

Acknowledgments

The idea of "writing a book" has changed considerably over the last several years. It used to be ink on paper, very straightforward. Now it's ink on paper, online content, clickable links, and the whole thing downloads to your phone. Two things I'm grateful for. First, I'm not responsible for most of that, and second, I have a whole bunch of help.

Those who do know about online content and clickable links—and typefaces, paper types, permissions, and everything else that goes into a book—are the remarkable people at McGraw Hill. It is impossible for me to thank them adequately, so I will thank them inadequately: Portfolio Manager Lauren Vondra, Lead Product Developer Krystal Faust, Sales Manager Tami Hodge, Project Manager Jeni McAtee, Content Licensing Specialist Lorraine Buczek, Designer David Hash, and Copy Editor Kevin Campbell. These are the hosts of the reality show *Let's Write a Textbook,* where they bring their considerable powers to bear on, well, me, I suppose. Without them, *Foundations in Microbiology* would not exist, and it is my great good fortune to work with them once again.

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

In this space I usually write something about microbiology being an invisible science, and despite our close and constant interactions with microorganisms of all sorts, the subject is the very definition of "out of sight, out of mind."

Not anymore.

The last 3 years have been dominated by one thing, and without setting foot in a micro classroom or reading a single textbook page, you've taken a crash course in at least some aspects of microbiology. You know about viral spikes, ivermectin, and herd immunity, and you've had more than one conversation with a stranger over the side effects of the Moderna versus Pfizer vaccines. You've received a scattershot course on microbiology, focused on a single organism (and most will say it's not an organism at all, but let us put off that discussion for six chapters) and driven in countless cases by people with an agenda that has nothing to do with facts. My hope is that we can improve upon that.

For most of you, this course is a required prerequisite for your chosen career, but microbiology is so much more. 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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Szasz-Fabian Jozsef/Shutterstock

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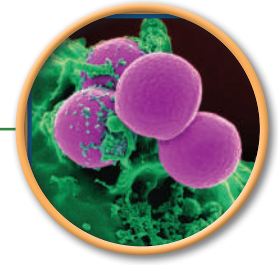
Jorgen Bausager/Folio Images /Getty Images

CHAPTER 6

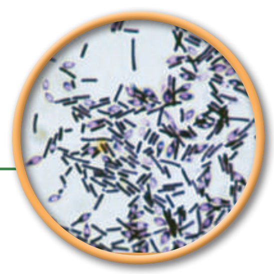
An Introduction to Viruses, Viroids, and Prions 166

Greg Knobloch/CDC

John Watney/Science Source



National Institute of Allergy and Infectious Diseases (NIAID)/NIH/USHHS



Richard Gross/McGraw Hill

CHAPTER 26

Robert Glusic/Digital Stock/Getty Images

CHAPTER 27

Barry Chess

CHAPTER

1

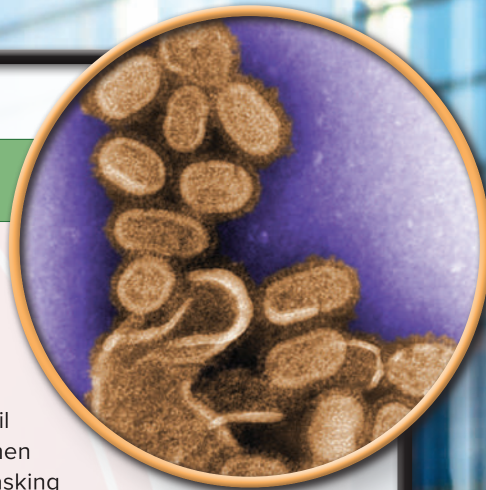
The Main Themes of Microbiology

In This Chapter...

A masked child stands in front of a closed movie theater in Seattle.

(Spanish Flu): *Vintage Space/Alamy Stock Photo;* (White wine): *John Thoeming/McGraw Hill;* (Mycobacterium): *Janice Carr/CDC;* (Algae unit): *INTREEGUE Photography/Shutterstock;* (female Aedes aegypti mosquito): *Frank Hadley Collins, Dir, Center for Global Health and Infectious Diseases; University of ND/CDC;* (Louis Pasteur): *Pixtal/age fotostock*

CASE STUDY Part 1 A Viral Pandemic



The origin of the **virus** will never be known for certain, and the first person in the United States to contract the disease is likely also lost to history. In the United States, cases first appeared in the Pacific Northwest, and the speed of the outbreak during March and April quickly outpaced early efforts to protect against the virus.

George Parrish, the health officer for Portland, Oregon, began a campaign to educate the public as to how the virus was transmitted, emphasizing the need to control **coughing and sneezing**, especially in crowded public places. He reached out to local religious leaders to help deliver the message from the pulpit to their congregations. A week after the first confirmed case in the city, the Oregon State Board of Health ordered the **shutdown** of all public gathering places; no restaurants, no theaters, and no school for tens of thousands of students. Officials reminded the public of the importance of **hand washing** and began a campaign to encourage **social distancing**. Two hundred miles to the north, Seattle had already seen a dozen deaths from the disease. The mayor asked that people avoid gathering in churches, and some public gatherings were banned entirely. On the opposite coast, the situation was no better as the White House, Congress, and the Supreme Court were closed to the public. When **masks** were found to reduce the risk of viral **transmission**, government agencies publicized their usefulness. The *San Francisco Chronicle* printed a public service announcement calling those who refused to wear masks “dangerous slackers” and emphasizing that beyond keeping oneself healthy, wearing a mask protected others who were more likely to suffer serious consequences. Shortly thereafter, the city of San Francisco passed a mask ordinance signed by the mayor and the board of health. The Red Cross stepped up to address a mask shortage in the city, distributing 5,000 masks in less than an hour, and 100,000 over the next 4 days. When a mask-buying frenzy left shelves bare, instructions were provided on how to make your own mask at home.

As the **pandemic** moved through a second **wave**, and then a third, fatigue set in. Despite the threat of fines, and even imprisonment in some cities, mask wearing was difficult to enforce, and people did not always adhere to social distancing recommendations. Across the country, politics intruded as people began to choose sides. In Portland, a city council debate became chaotic when one member decried a masking order as “autocratic and unconstitutional,” adding that “under no circumstances will I be muzzled like a [rabid] dog.” In San Francisco, 2,000 people gathered indoors to join an anti-mask rally, which included physicians, as well as one member of the Board of Supervisors. Public outcry grew louder when several city officials, including the mayor, were photographed attending a boxing match without masks. The situation in San Francisco came to a head when a special officer for the Board of Health shot a man in a dispute over mask-wearing (he survived but was arrested for not following the officer’s orders).

Because most **public health** decisions were made at the local level, the success of mitigation strategies varied wildly. Health officials in Philadelphia advised the mayor to cancel several large public gatherings, including a parade, to prevent the spread of the virus. The mayor refused, and a surge in cases followed. Meanwhile, in St. Louis, similar gatherings were quickly shut down, robbing the virus of an opportunity to spread. In the end, St. Louis had one-eighth as many deaths as did Philadelphia. While most medical experts recommended **quarantines** and face masks, health officials in many cities, according to the *New York Times,* “opposed both these measures and placed great reliance on [the development of a] **vaccine**.”

The year was 1918. The wait for a vaccine would be 25 years.

- *What branch of microbiology focuses on the spread of disease in communities?*
- *How does an endemic disease differ from a pandemic disease?*

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

Influenza virus particles

(inset) Cynthia Goldsmith/Centers for Disease Control and Prevention; DigitalMammoth/Shutterstock

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.

Put simply, you can always tell when there is an elephant in your living room. But for every elephant, oak tree, or person, there are billions of microbes. These microorganisms hide in plain sight, concealed by their small size. And whether we search for them beneath the polar ice caps, in toxic waste dumps, or in a bottle of kombucha, they are present. Microbes are **ubiquitous.***

Microbiology is a specialized area of biology that deals with these tiny life forms that are not readily observed without magnification, which is to say they are **microscopic.*** And whether we call them **microorganisms,** or **microbes,*** their effects are clearly much greater than their size. The major groups of microorganisms include **bacteria, viruses, fungi, protozoa, algae,** and **helminths** (parasitic worms). 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.

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 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**

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

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

TABLE 1.1 A Sampling of Fields and Occupations in Microbiology

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.
Scott Bauer/USDA

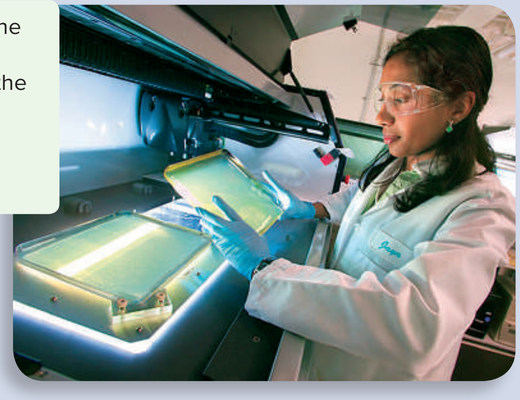
Immunology

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.
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.
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.
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.
Keith Weller/USDA

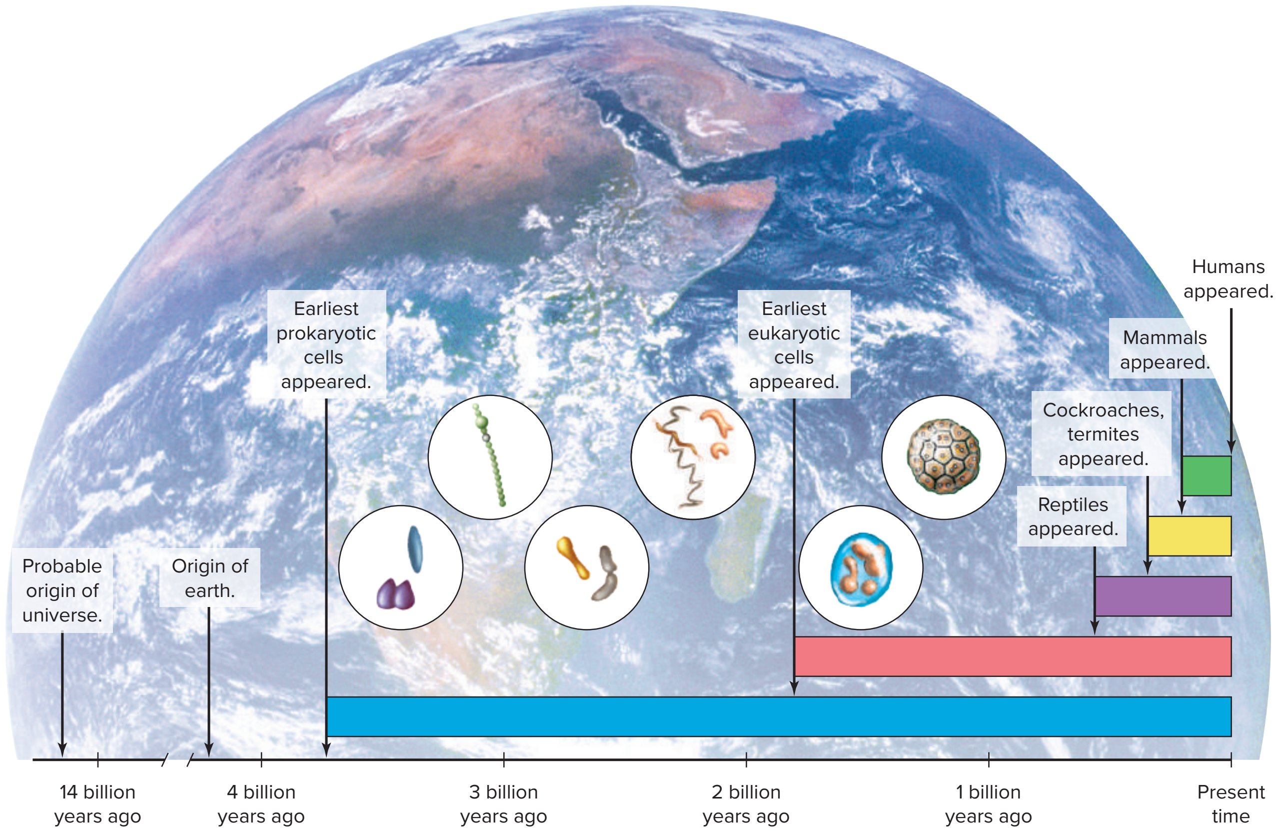


Figure 1.1 **Evolutionary time line.** The first simple prokaryotes appeared on earth approximately 3.5 billion years ago, and the first eukaryotes arose about 2 billion years ago. Although these appearances seem abrupt, hundreds of millions of years of earth's history passed while they were evolving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

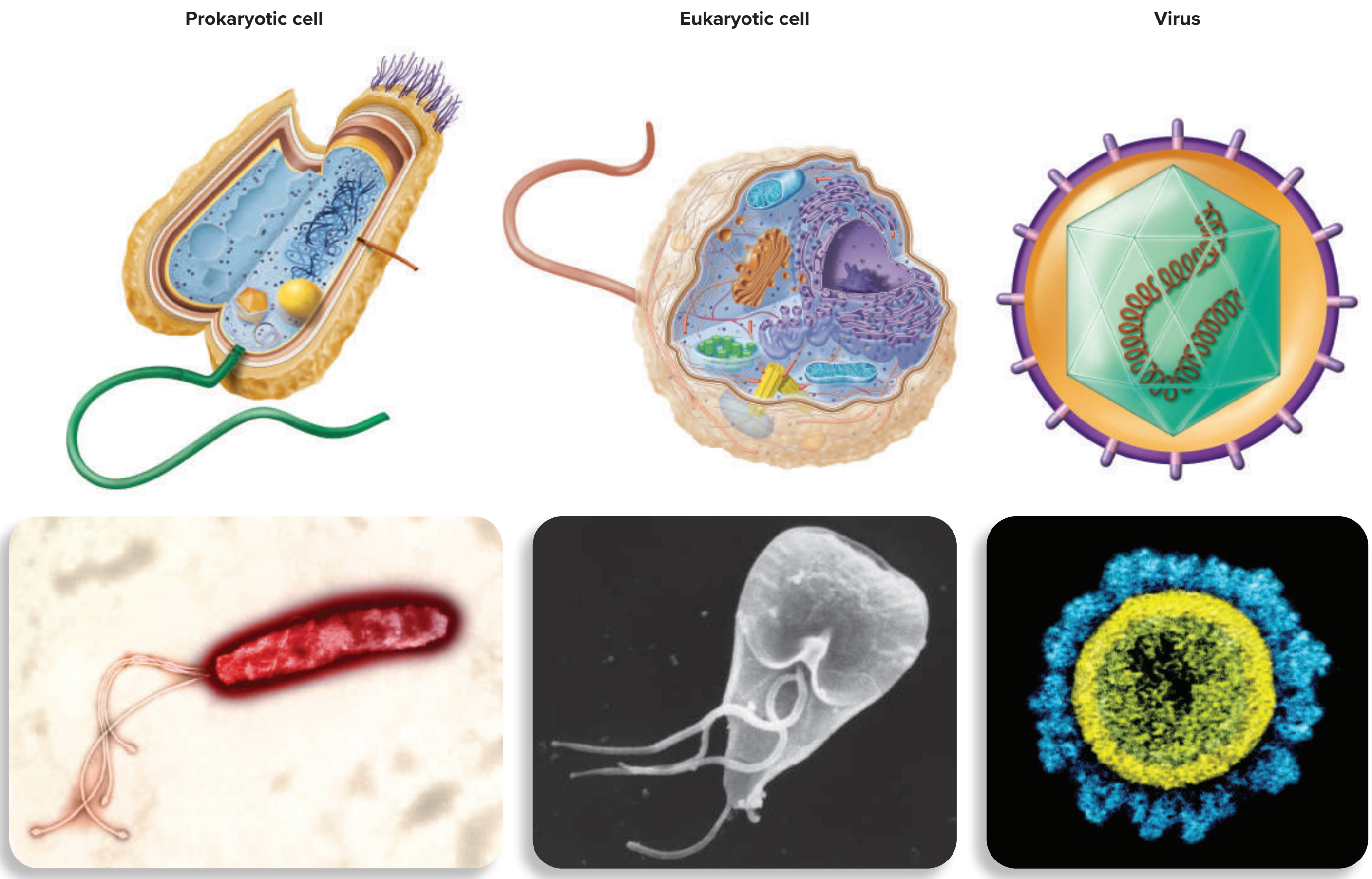


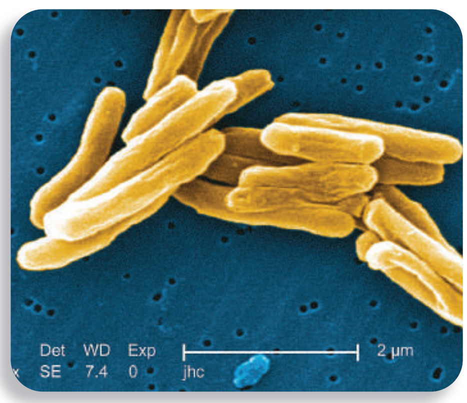
Figure 1.2 **Basic structure of cells and viruses.** Diagrammatic views of prokaryotic and eukaryotic cells, along with a virus compared to electron micrographs of *Helicobacter pylori* (left), *Giardia lamblia* (center), and SARS-CoV-2 (right).
(helicobacter pylori bacterium): Heather Davies/Science Photo Library/Science Source; (giardia lamblia): Janice Haney Carr/CDC; (transmission electron micrograph): NIAID

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. Considering their long evolutionary history, they are essential to maintaining the health of the planet.

The Cellular Organization of Microorganisms

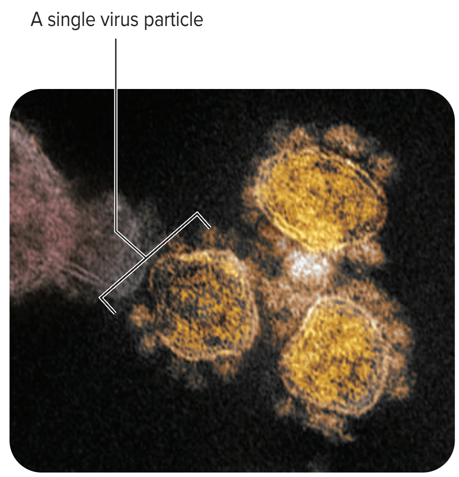
Prokaryotic cells are nearly always smaller than eukaryotic cells and in addition to lacking a nucleus, they lack organelles. Organelles are small membrane-enclosed structures that perform specific functions, such as converting energy (in mitochondria) or modifying proteins (in Golgi apparatus). Although prokaryotic cells perform similar functions, they tend to do so less efficiently because they lack organelles.

Prokaryotes are all microscopic in size and generally found as single cells. The much larger eukaryotes run the gamut from small, individual cells to large multicellular organisms **(figure 1.3)**. The study of microbiology focuses not just on microscopic, prokaryotic organisms like bacteria, but also on those larger eukaryotes that are linked to illness or the spread of disease; hence a microbiologist may be interested in parasitic worms, or mosquitoes, ticks, and fleas that may spread infectious disease. A third group of organisms, archaea, are often grouped together with the bacteria because they share several characteristics. From a health standpoint, though, few if any diseases are linked to the archaea, and so we will refrain from using the name *archaea* unless we specifically wish to draw attention to those microbes. Just keep in mind that many traits ascribed to bacteria also apply to archaea.

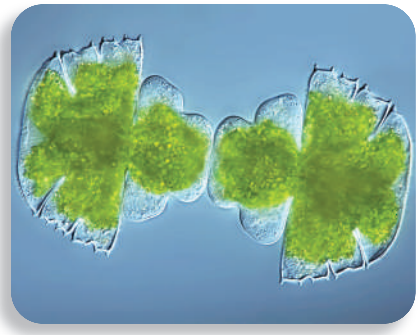


Bacteria: *Mycobacterium tuberculosis,* a rod-shaped cell (15,500×).

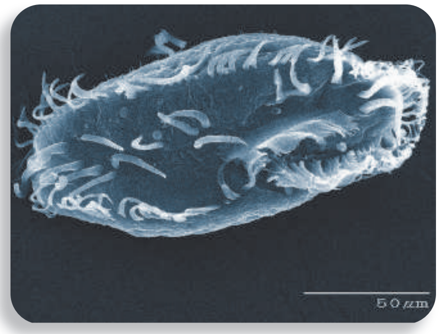
Fungi: *Rhizopus*, the common fungus seen on bread, with lollipop-like reproductive structures (1,000×).



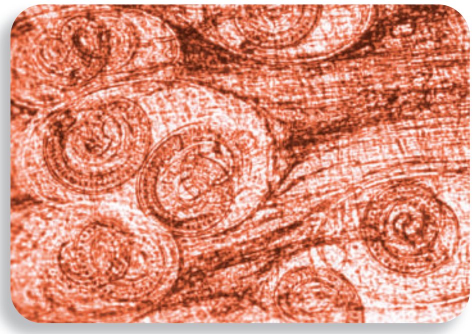
Virus: SARS-CoV-2, the cause of COVID-19 (100,000×).



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



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): Janice Carr/CDC; (fungi): Rattiya Thongdumhyu/Shutterstock; (virus): NIAID-RML; (algae): Lebendkulturen.de/Shutterstock; (protozoa): National Human Genome Research Institute; (helminths): Centers for Disease Control and Prevention

Noncellular Pathogenic Particles—Viruses and Prions

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

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

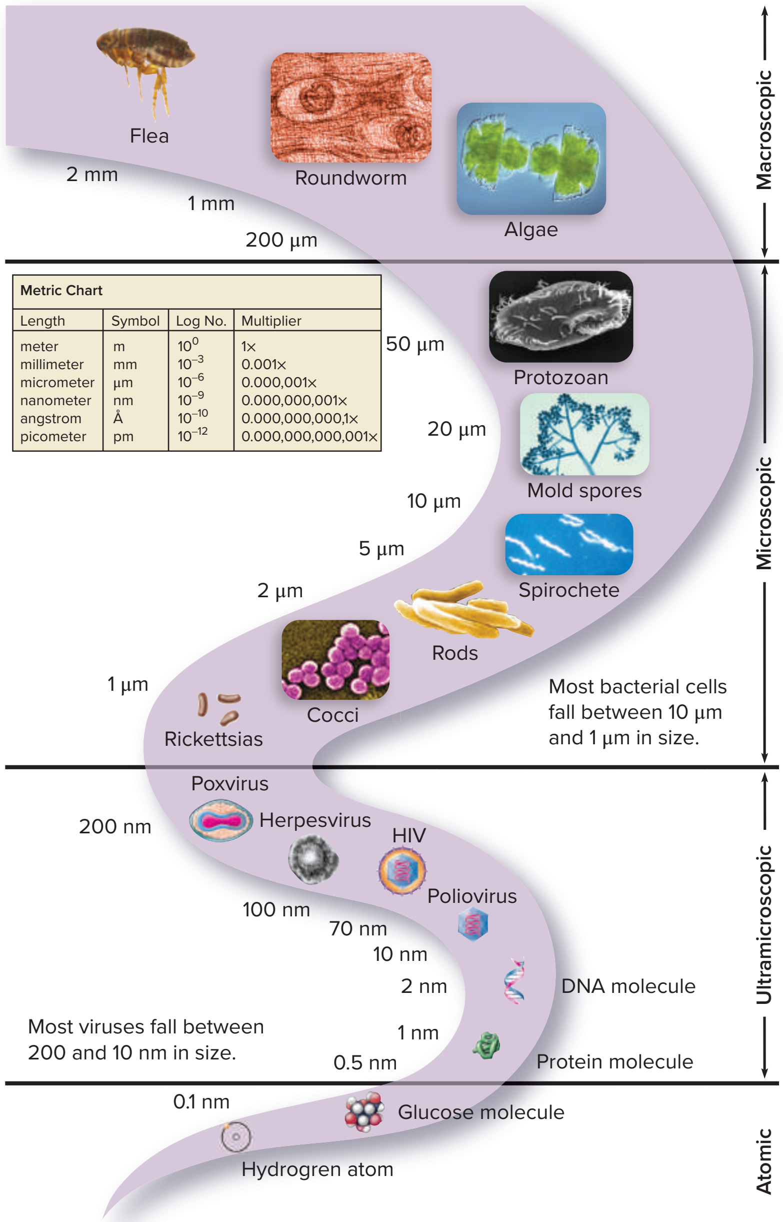
Microbial Dimensions: How Small Is Small?

When we say that microbes are too small to be seen with the unaided eye, what sorts of dimensions are we talking about? This concept is best visualized by comparing microbial groups with some organisms of the macroscopic world and also with the molecules and atoms of the molecular world **(figure 1.4).** The dimensions of macroscopic organisms are usually given in centimeters (cm) and meters (m), whereas those of most microorganisms fall within the range of micrometers (μm) and, sometimes, nanometers (nm) and millimeters (mm). The size range of most microbes extends from the smallest viruses, measuring around 10 nm and actually not much bigger than a large molecule, to protozoans measuring 3 to 4 mm and visible with the naked eye.

Microbial Involvement in Energy and Nutrient Flow

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

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



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): Centers for Disease Control and Prevention; (algae): Lebendkulturen.de/Shutterstock; (protozoan): National Human Genome Research Institute; (mold spores): Dr. Lucille K. Georg/CDC; (spirochete): CDC; (rods, cocci): Janice Carr/CDC; (herpesvirus): Jeff Hageman, M.H.S/Janice Carr/CDC

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

CLINIC CASE

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

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

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

Speculate on why algae blooms, like the ones in 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 diseases. Microbes form similar interrelationships with animals, notably as residents of numerous bodily sites.

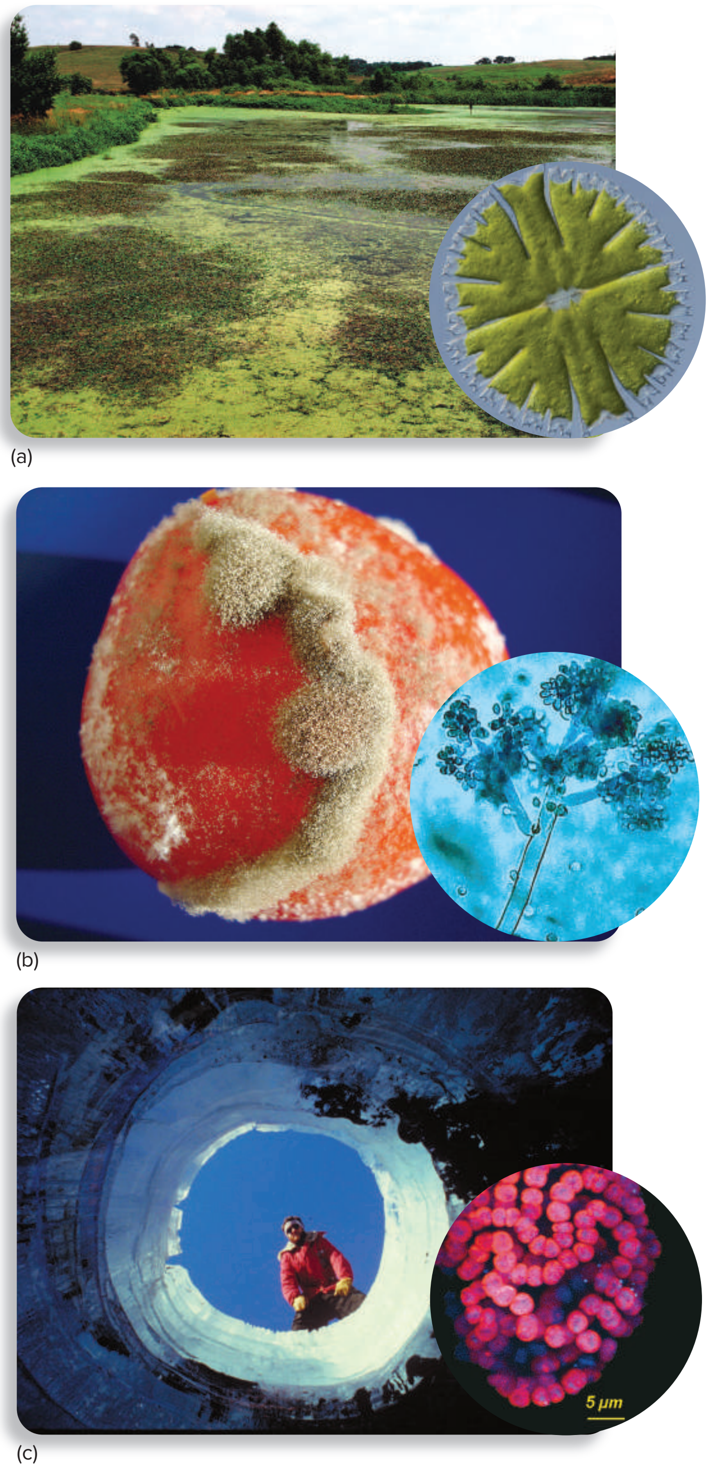


Figure 1.5 A microscopic world tour. **(a)** A summer pond is heavily laden with surface scum that reveals several different types of green algae called desmids (*Micrasterias rotata,* 600×). **(b)** A rotting tomato being invaded by a fuzzy forest of mold. The fungus is *Botrytis,* a common decomposer 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. *Nostoc,* a red cyanobacterium (3,000×), has been frozen beneath the ice here for thousands of years. This environment may serve as a model for what may one day be discovered on other planets.

(a): Lynn Betts, USDA Natural Resources Conservation Service; (a, inset): Lebendkulturen.de/Shutterstock; (b): McGraw Hill; (b, inset): McGraw Hill; (c): 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

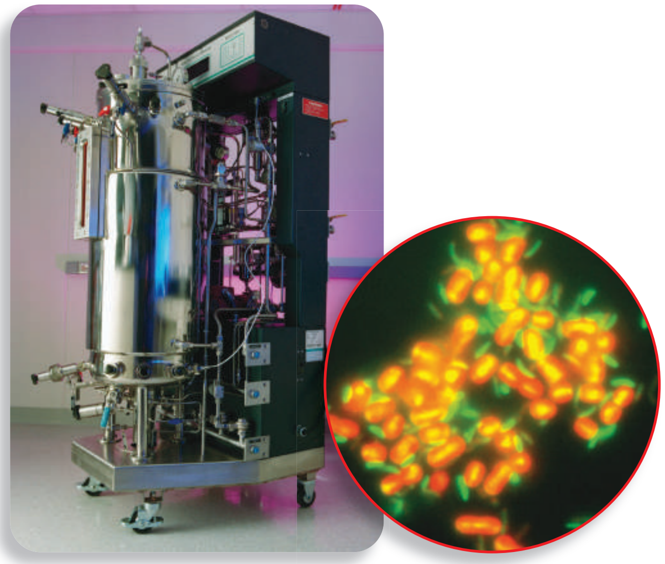
Learn

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 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 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 an area of biotechnology in which the goal is to alter the genetic material of microbes, plants, or animals. Often this involves combining DNA[2] from multiple species, creating **recombinant DNA**. These recombinant organisms may be useful by themselves, or they may produce useful products, such as bacteria that produce enzymes or hormones for human use. Bacteria and fungi were the first organisms to be genetically engineered because their relatively small genomes were more readily manipulated in the laboratory. This technology has unlimited potential for medical, industrial, and agricultural uses (see table 1.1).

(a)



(b)

Figure 1.6 Microbes at work. (a) Algae being used as a sustainable alternative to fossil fuels. **(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): INTREEGUE Photography/Shutterstock; (b): *Source:* Pacific Northwest National Laboratory; (b, inset): 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.

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

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

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

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

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 1,500 different pathogens and, worldwide, 10 million people a year die from infectious disease. Most of these deaths are attributable to a small number of infectious agents and are concentrated in developing countries. Many of earth's 8 billion inhabitants are malnourished, not fully immunized, and have little access to drugs, leaving them far more vulnerable to infections of all types. **Table 1.2** 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. Or take the case of malaria, caused by a microorganism transmitted by mosquitoes, which kills 400,000 people every year worldwide. Currently the most effective way for citizens of developing countries to avoid 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 many people in developing countries who cannot afford the $3 to $5 for nets to protect their families.

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 1.2 Treatable or Preventable Neglected Tropical Diseases

Disease	Number of Cases
Ascariasis	1,000,000,000
Hookworm infection	700,000,000
Onchocerciasis (river blindness)	20,900,000
Lymphatic filariasis	51,000,000
Schistosomiasis	240,000,000
Trachoma	2,000,000

Quick Search
Nothing But Nets was started by sports columnist Rick Reilly in 2006 and has raised more than $70 million for insecticide-treated bed nets. www.nothingbutnets.net

The Changing Specter of Infectious Diseases

The widespread use of antibiotics and vaccines over the last several decades has done much to alleviate the suffering caused by infectious disease. In 2022, 7 of the 10 leading causes of death worldwide were noncommunicable diseases—heart disease, stroke, and chronic obstructive pulmonary disease top the list. Simultaneously, HIV/AIDS deaths have fallen dramatically, dropping the disease from 8th to 19th over the last 20 years. But a closer look reinforces the fact that the playing field is not level. In low-income countries, neonatal infections, lower respiratory infections (bronchitis, pneumonia), diarrheal disease, malaria, tuberculosis, and HIV/AIDS all remain among the 10 leading causes of death, quite different from what is seen in high-income countries **(figure 1.7)**. 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 90 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. SARS-CoV-2, the virus that causes COVID-19, 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.

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

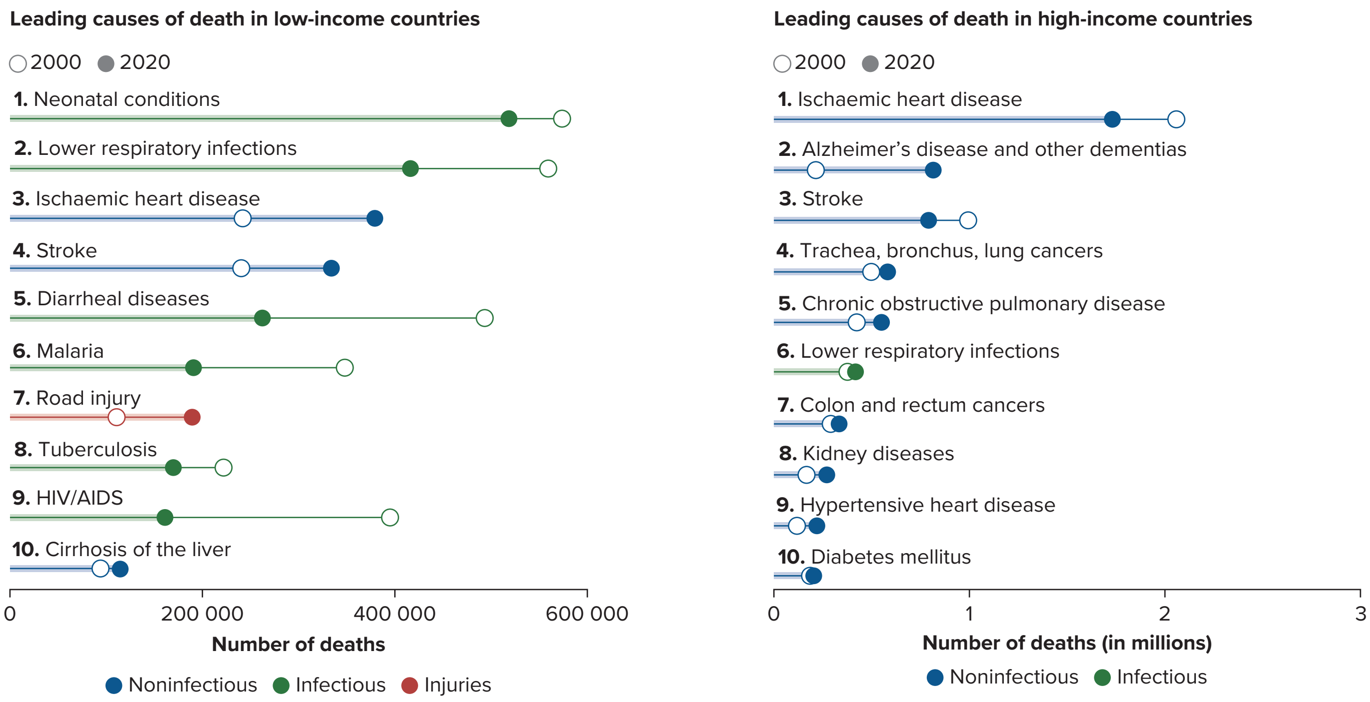


Figure 1.7 **The burden of infectious disease.** As the average income of a country increases, the risk of death from infectious disease decreases dramatically. Chronic diseases, many of which occur later in life, take a much greater toll in developed countries.

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 10 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.

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.
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 Diseases

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 strategies–drugs, vaccines, or something else–are used to combat each one.
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.

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.

The Scientific Method and the Search for Knowledge

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

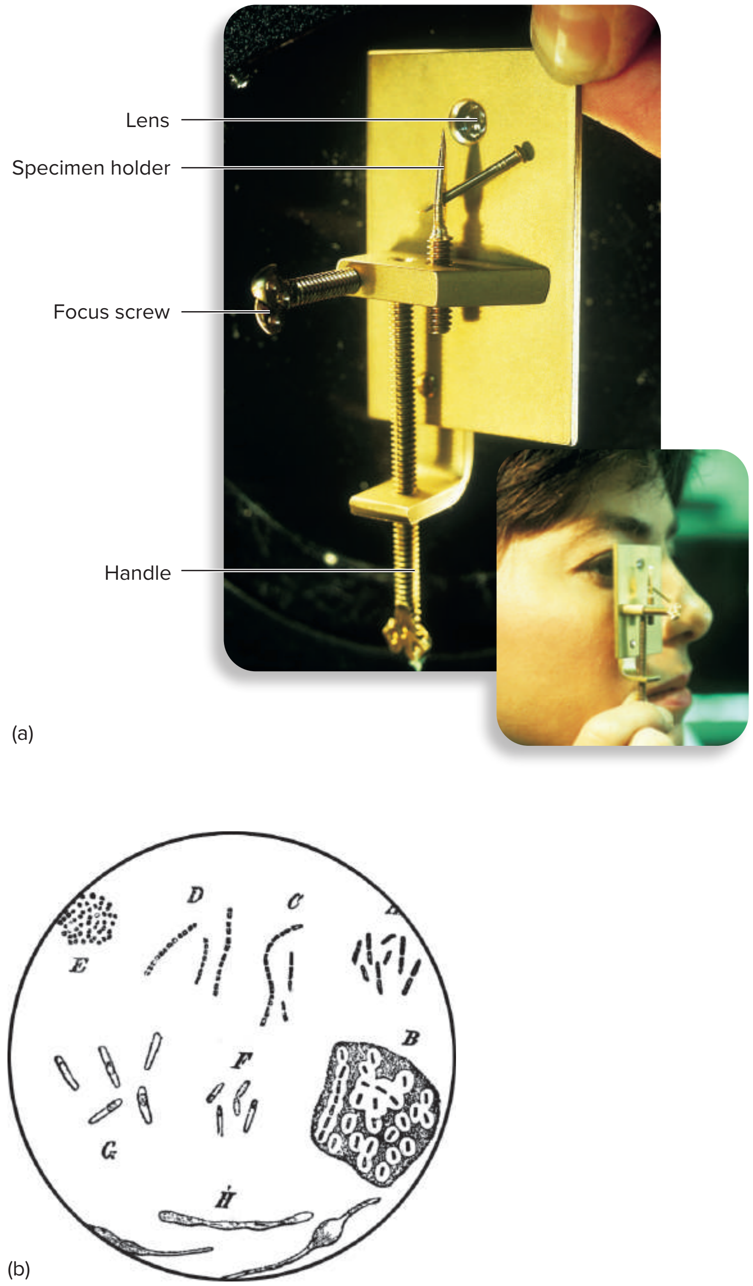


Figure 1.9 Leeuwenhoek's microscope. (a) A brass replica of a Leeuwenhoek microscope and how it is held (inset). **(b)** Early illustrations of bacterial cells from a sample of milk, magnified about 300×. These drawings closely resemble those Leeuwenhoek made of his animalcules.

(a): McGraw Hill; (a, inset): McGraw Hill

or myth. A valid hypothesis will allow for experimentation and testing and can be shown to be false. An example of a workable 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.

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.

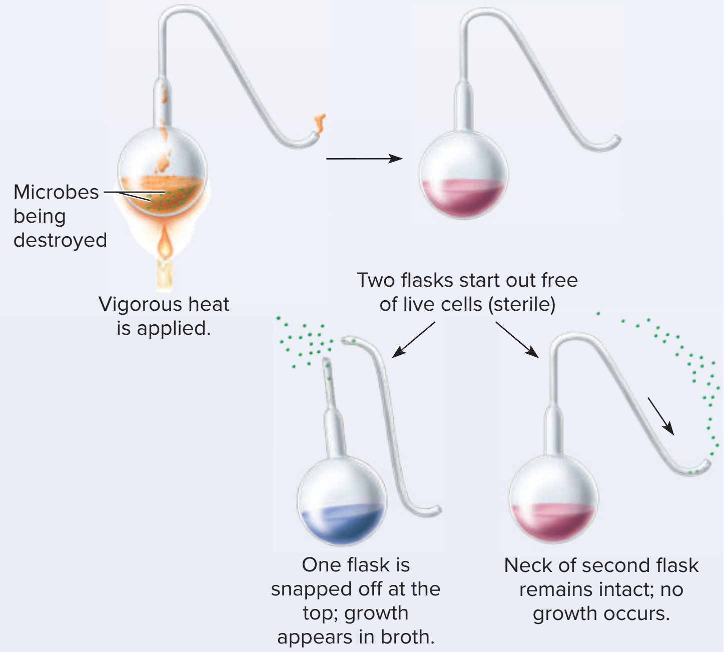
Over the subsequent 200 years, scientists waged an experimental battle over the two hypotheses that could explain the origin of simple life forms. Some tenaciously clung to the idea of **abiogenesis,*** which embraced spontaneous generation. On the other side were advocates of **biogenesis,*** saying 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 for 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.

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. While theories explain *why* things happen, **laws** are more concerned with *how* they happen. Laws usually involve a good deal of mathematics, like Einstein's $E = mc^2$. Because living systems are not uniform—human beings, for instance, have different heights and weights, and different life spans—accurate mathematical representations are difficult. These vagaries mean that laws cannot always be developed, and consequently we have fewer laws in biology than in physics, for example. Still, no serious scientist doubts the germ theory of disease, or the theory of evolution by natural selection.

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 development of vaccines. What is remarkable about Jenner's work is that he used scientific thought to construct an experimental model to inoculate people against disease. 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.

Onesimus and Variolation

In 1706, Cotton Mather, a Puritan minister in Boston, was presented with—as a gift from his congregation—an enslaved West African man who he named Onesimus, a reference to a similarly enslaved man in the Bible, whose name meant "useful." Onesimus told Mather that he had undergone a procedure in Africa that protected him against smallpox. The procedure was simple enough, pus from an infected person was rubbed into an open wound on the arm of the person to be protected. Most of the time, the recipient's immune system was activated, and they were protected against disease. Mather was convinced, especially after learning that the practice had long been used in Turkey and China, but others weren't, vilifying any procedure developed by or for Black people.

In 1721 a smallpox epidemic hit Boston, spreading rapidly through the population. Mather, with the help of Zabdiel Boylston, the only physician in Boston who supported the technique, inoculated 242 people, including his son and his own enslaved workers. In the end, only 1 in 40 variolated persons died as opposed to 1 in 6 of those who didn't undergo the procedure. Onesimus and variolation set the stage for Edward Jenner and his work on a smallpox vaccine.

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 that Jenner's work 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. 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

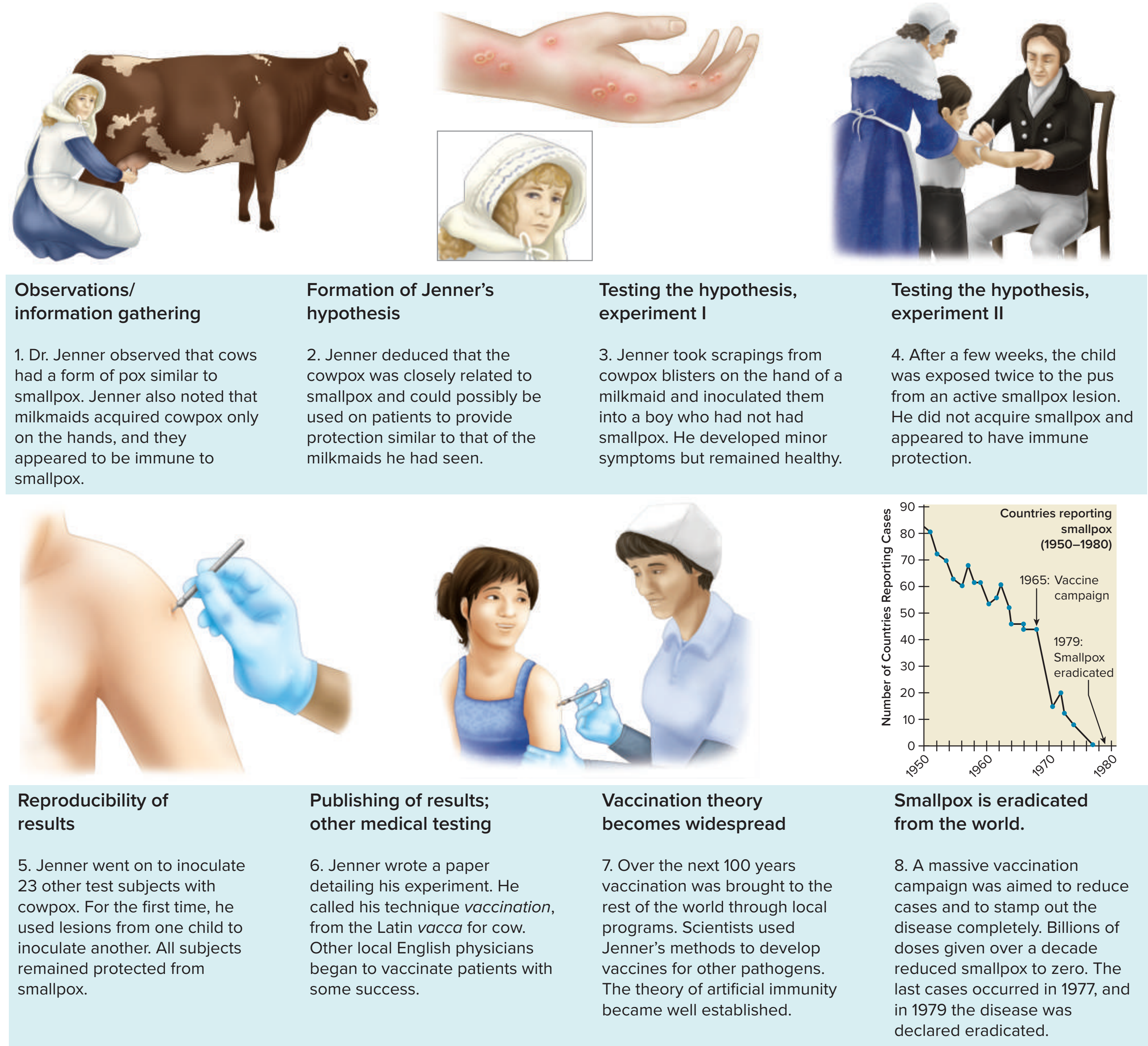


Figure 1.10 Edward Jenner and the saga of the smallpox vaccine. Jenner's work documents the first attempt based on the scientific method to control an infectious disease—smallpox. This disease was characterized by raised skin blisters called pox, and it often caused severe damage to organs. Throughout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

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 some that the human body itself could be 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.

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

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

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 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).

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

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? Justify your answer.
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

* *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.

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 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.

* *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.

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. In the past a microbe may have been named after a prominent person (often a microbiologist) or a location where the microbe was found, though this is less often the case today **(1.2 Making Connections).** Other names may designate a characteristic of the microbe (shape,

* *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.

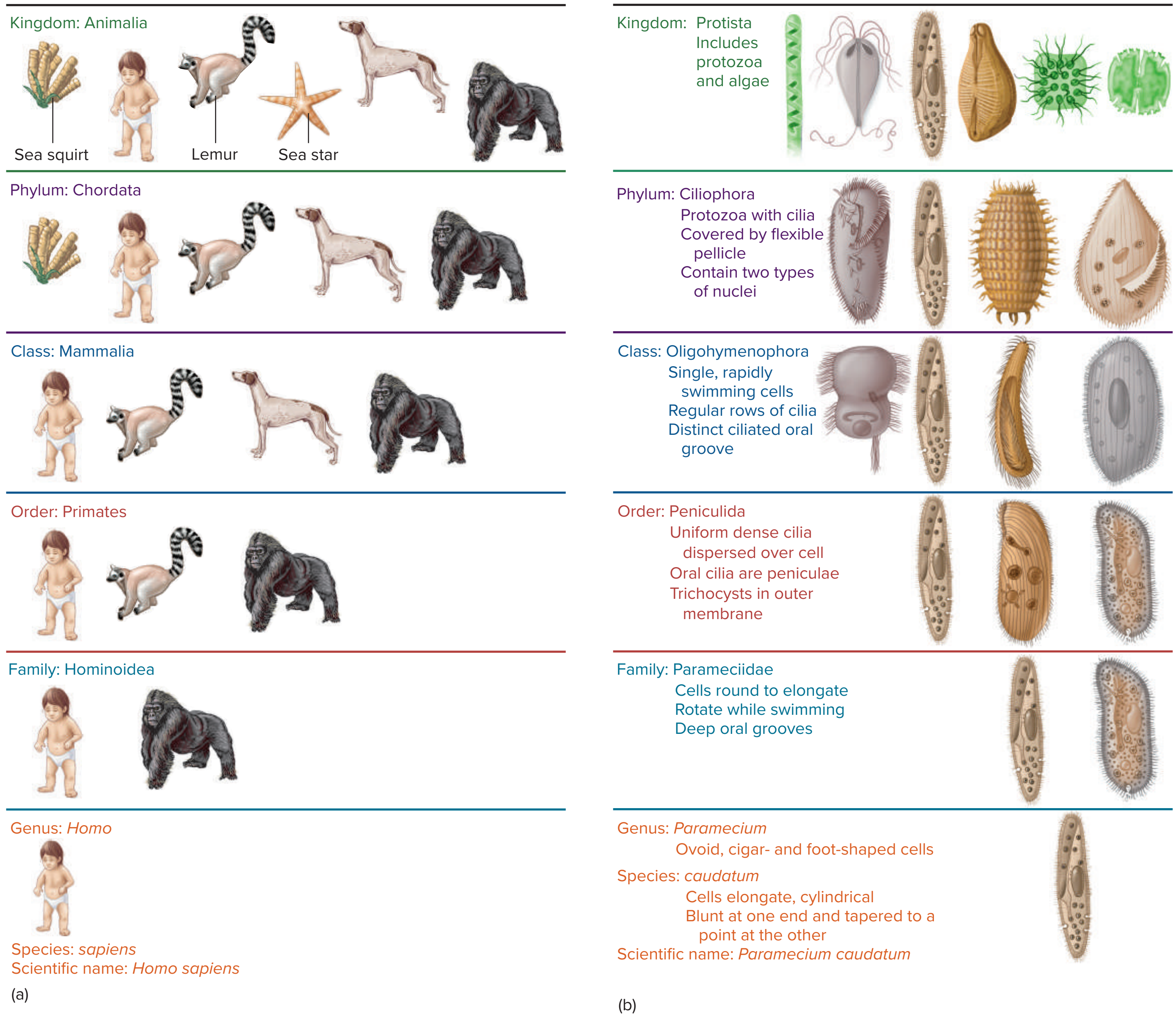
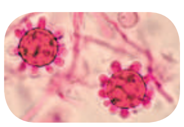
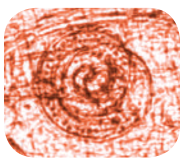


Figure 1.12 Sample taxonomy. Two organisms belonging to Domain Eukarya, traced through their taxonomic series. **(a)** Modern humans, *Homo sapiens.* **(b)** A common protozoan, *Paramecium caudatum.*

color), or a symptom of infection. Some examples of scientific names and origins are:



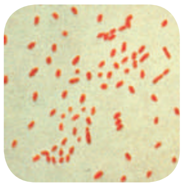
1. ***Histoplasma capsulatum*** Gr. *histo,* tissue, *plasm,* to form, and L. *capsula,* small sheath. A fungus that causes Ohio Valley fever.



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. Centers for Disease Control and Prevention

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

1.2 MAKING CONNECTIONS

A More Inclusive WHO

Most of us are well acquainted with the derogatory names associated with SARS-CoV-2; China flu, Chinese virus, Kung flu, some even worse. We're also familiar with racist acts—from rudeness to murder—committed by people who thought their actions were somehow justified based on the origins of the virus. But a debate over the naming of SARS-CoV-2 tells only a part of the story.

The general rule on naming an organism is that if you discovered it, you get to name it. But because the World Health Organization generally takes the flak when a name proves offensive, the WHO has always had a hand in the name game. For more than a century most new organisms were named after people, places, and animals, giving us *Salmonella* (after David Salmon), Marburg virus (a city in Germany), and swine (pig) flu. Unfortunately, this strategy also gave us GRID (gay-related immune deficiency) an early name for AIDS. Did the name Norwalk virus reduce property values in Norwalk, Ohio? Did hog farmers lose money when swine flu was named? The answer to both questions is almost certainly yes.

In 2015, the WHO released updated guidance for the naming of newly discovered pathogens that affect humans. People, places, and animals were out, as were occupations, food, and terms that incite fear, like fatal or epidemic. The new rules relied on symptoms (respiratory disease, diarrhea) along with epidemiological terms (seasonal, severe, juvenile). Hence, severe acute respiratory syndrome associated coronavirus type 2, or SARS-CoV-2. The WHO, by the way, does not advocate renaming pathogens or diseases with names already established in the literature. Ebola virus and Chagas disease are here to stay.

While certainly more respectful of people's feelings, there are many microbiologists who feel that the new rules produce names lacking poetry; that Rocky Mountain spotted fever is just an inherently more interesting name than maculopapular rash disease, type 11 (or something similar). Others, like Columbia University virologist Ian Lipkin, feel that the new name recommendations obscure relevant facts, saying "I don't see how it will be helpful to eliminate names like monkey pox, that provide insights into natural hosts and potential sources of infection." And sometimes the best of intentions just don't work out. SARS, a name designed not to offend, did not go over well in Hong Kong, which is officially known as the Hong Kong special administrative region, or SAR.

Delta Airlines likely lost money due to a particularly virulent strain of SARS-CoV-2 being named the delta variant (after Delta, the fourth letter of the Greek alphabet). Should the airline have any recourse to recover lost money from the U.S. government or World Health Organization? (Recall that the U.S. government distributed billions of dollars to businesses that were hurt by the pandemic.)

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

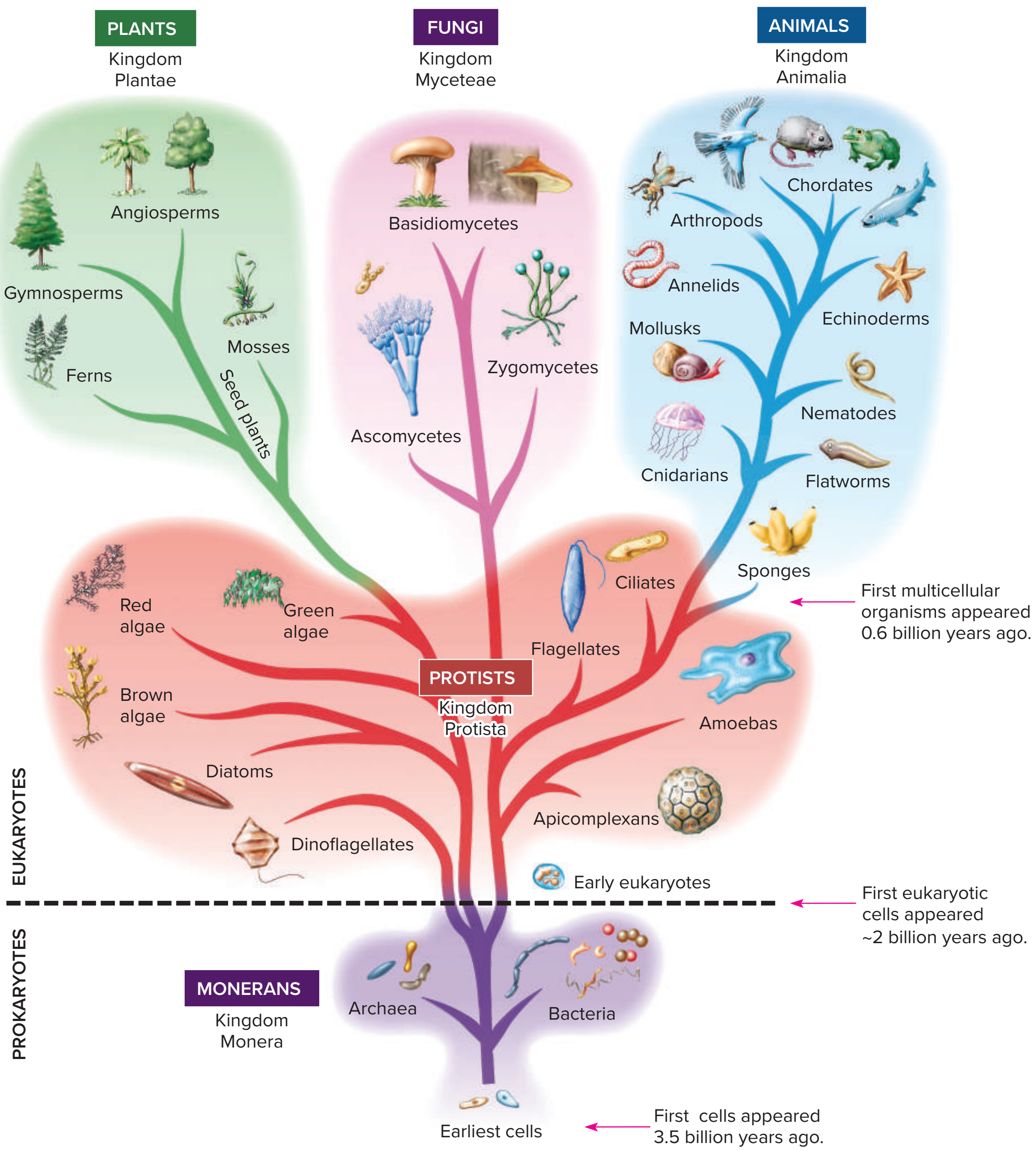


Figure 1.13 **Traditional Whittaker system of classification.** In this system, kingdoms are based on cell structure and type, the nature of body organization, and nutritional type. Bacteria and Archaea (monerans) have prokaryotic cells and are unicellular. Protists have eukaryotic cells and are simple 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.

theme that underlies all of biology, including microbiology. Put simply, the scientific principle of evolution states that living things change gradually over time. Those changes that 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 and (2) that closely related organisms have similar features because they evolved from a common ancestor. Organisms typically become more complex as they evolve.

Traditionally phylogeny, or the history of life, is presented 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, with organisms becoming evolutionarily younger as one moves

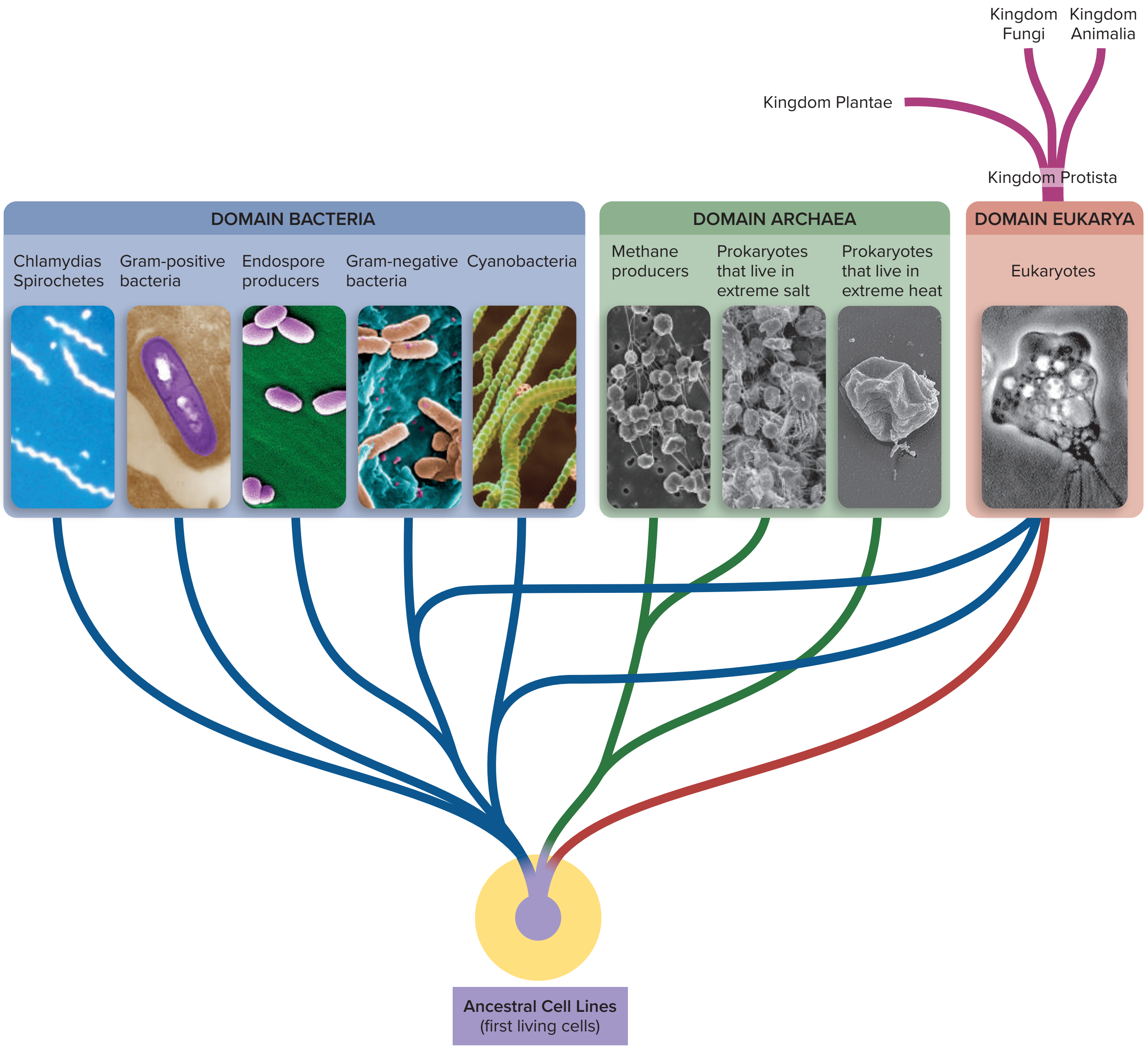


Figure 1.14 **Woese-Fox system.** A system for representing the origins of cell lines and major taxonomic groups as proposed by Carl Woese and colleagues. They propose three distinct cell lines placed in superkingdoms called domains. We know little about the earliest cells, called progenotes, except that they were prokaryotic. Lines of these early primitive cells gave rise to the Domains Bacteria and Archaea. Molecular evidence indicates that the Archaea started the branch that would eventually become the Domain Eukarya. Notice that two early bacterial lines contributed to the evolution of the Eukarya. Selected representatives of the domains are included. The traditional eukaryotic kingdoms are still present with this system (see figure 1.13). Further details of classification systems are covered in chapters 4 and 5.
(1): CDC; (2): CDC/Dr. Balasubr Swaminathan & Peggy Hayes, photo by Elizabeth White; (3): Laura Rose & Janice Haney Carr/CDC; (4): Janice Haney Carr/CDC; (5): Steve Gschmeissner/Science Photo Library/Getty Images; (6, 7): Maryland Astrobiology Consortium, NASA and STScI; (8): From *Stand Genomic Sci.* 2011 July 1;4(3): 381–392 doi: 10.4056/sigs.2014648; (9): CDC-DPDx

upward; branches split off the main trunk as evolution continues. In 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 shared biological characteristics (dog, wolf, coyote, fox), 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