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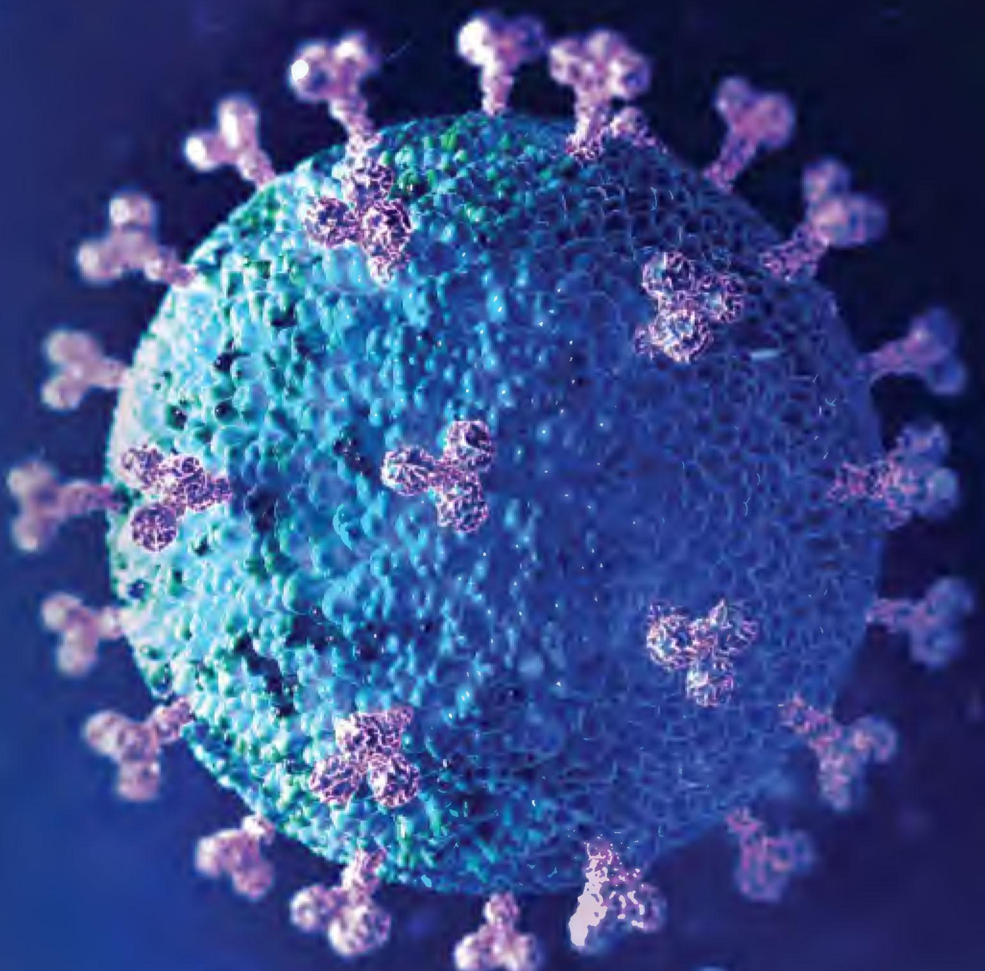
Fundamentals of MICROBIOLOGY



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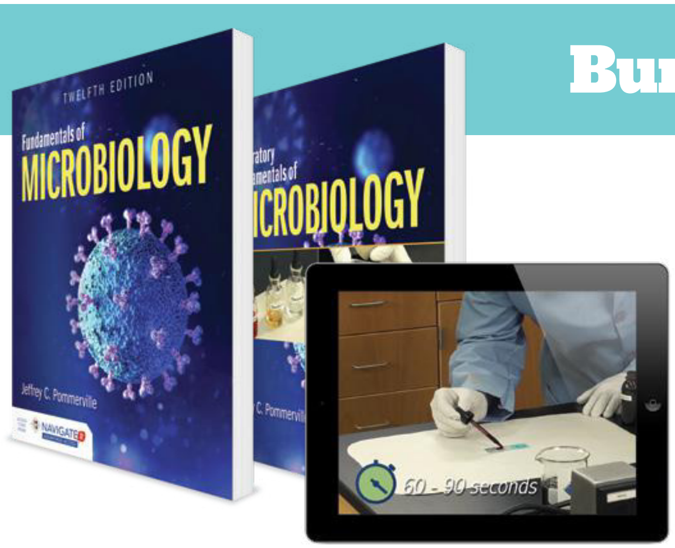

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TWELFTH EDITION

Fundamentals of MICROBIOLOGY

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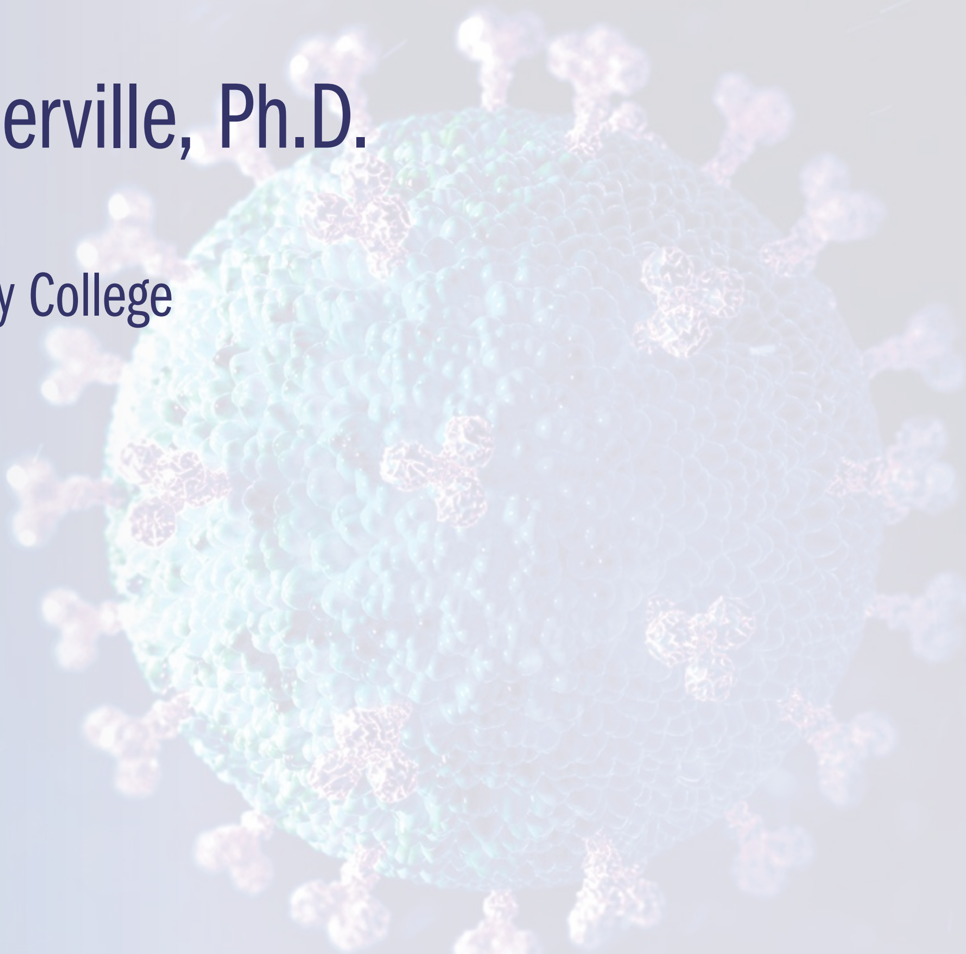

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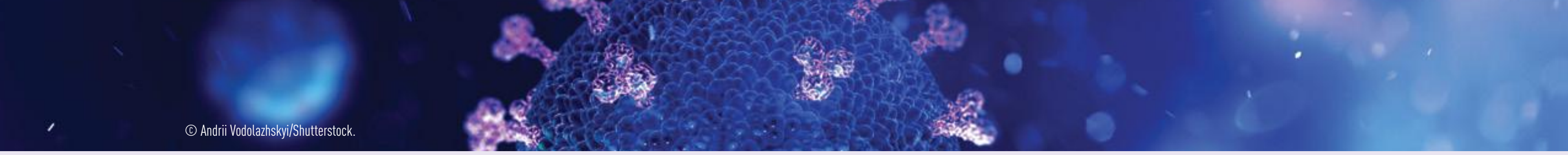
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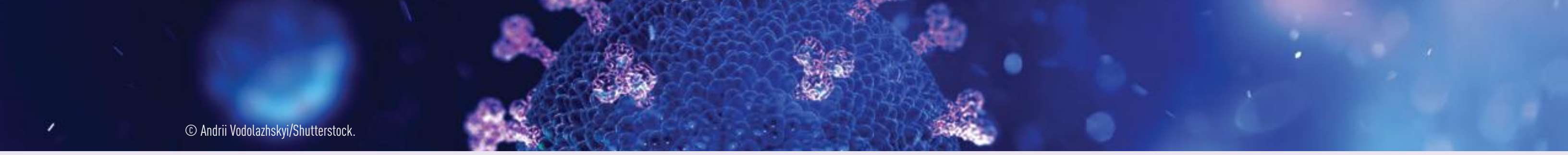

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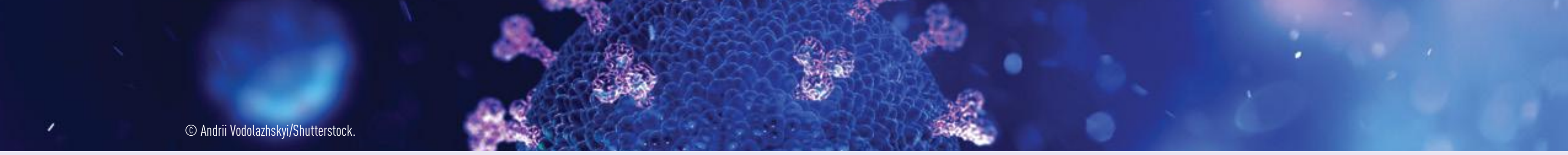

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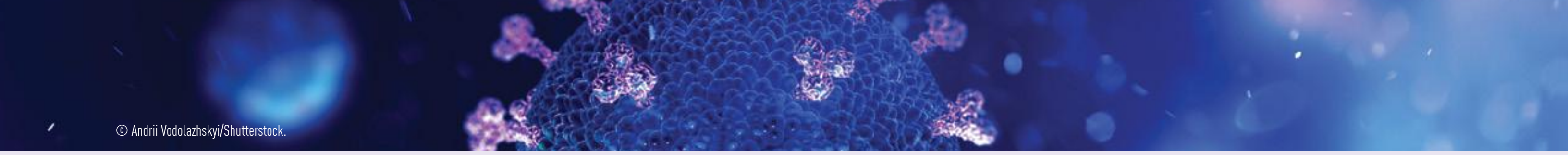

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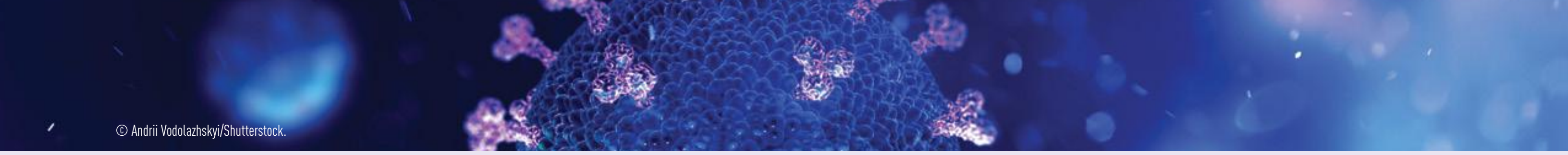


Preface

Teaching and Learning in the Time of COVID-19

What a difference an edition makes. In the preface to the previous edition of *Fundamentals of Microbiology*, I remarked that

> "Today … despite extraordinary advances to eliminate or lessen the development and spread of infectious disease, their appearance continues—and indeed, it is inevitable." I went on to say that "more than 60% percent of new human infections originate in, or are transmitted by, wild animals, [including] AIDS (apes and monkeys to humans), SARS and Ebola (bats [to other animals] to humans), and Zika (monkeys to mosquitoes to humans). Consequently … unknown infectious microbes in wild animals will 'jump' to humans as these interacting species make contact … adding to these factors is the globalized world we live in today. Airline travel makes an infectious disease outbreak in one corner of the world only a day's plane ride from almost any other destination on the globe. Accordingly, infectious diseases can 'pop up' from seemingly nowhere."

Many disease experts around the world for decades have said that it is not *if* a disease pandemic will happen, but rather *when* it will happen. And, so it has in the form of coronavirus disease 2019 (COVID-19).

I went on to echo the thoughts of numerous health experts that

> "Each new emerging disease brings unique challenges, forcing the medical community to continually adapt to these ever-shifting threats. The battle against emerging infectious diseases is a continual process in trying to get ahead and stay ahead of the next infectious agent before it can explode on the world scene."

Unfortunately, that next infectious agent has exploded on the world in the form of the SARS-CoV-2 virus, the infectious agent for COVID-19. It certainly has brought many new challenges to every aspect of work, school, economics, health care, and societal behaviors (social distancing, wearing masks, etc.). All of us have and will continue to be impacted in every aspect of our lives by this disease.

Another major change in these pandemic times has affected higher education. Community colleges, four-year colleges, and universities have scrambled to get courses online, and many students have experienced this new paradigm to higher education by finishing and taking classes and labs online. I suspect the traditional format for higher education might never be quite what it was in the past. An important aspect of this change is flexibility, a characteristic that both students and instructors must have, as all struggle to deal with ensuing educational changes.

In the process of teaching and learning, our age of social media has brought many instances of misinformation/disinformation about many aspects of science. In microbiology, this includes COVID-19, its origin and spread, and value of vaccination in general as well as to COVID-19 specifically. Therefore, one key to the new era of learning and teaching in this "infodemic" world will be sources of trusted and accurate information outside the classroom. I believe that beyond the instructor, the college textbook remains the best, most authoritative source of information to provide the flexibility and foundation for the new education experience involving distance learning.

Fundamentals of Microbiology, Twelfth Edition provides that essential role and need. Besides the fundamental microbiological and disease aspects of COVID-19, which are discussed throughout the pages of this current edition, the textbook is an important tool for student learning in microbiology. It consolidates the important concepts and ideas necessary for mastery by students entering the health care field as a nurse or other allied health professional. Over many editions of *Fundamentals of Microbiology*, the textbook has reflected flexibility by evolving in response to the rapidly changing field of microbiology and the changing learning needs of students. I hope that you will find *Fundamentals of Microbiology*, *Twelfth Edition* welcoming and informative as you explore the amazing world of microbiology.

A Concept-Based Curriculum

Fundamentals of Microbiology, Twelfth Edition is written for introductory microbiology courses having an emphasis in the health sciences. It is geared toward students in health and allied health science curricula such as nursing, dental hygiene, medical assistance, sanitary science, and medical laboratory technology. It also will be an asset to students studying food science, agriculture, environmental science, and health administration. In addition, the text provides a firm foundation for advanced programs in biological sciences, as well as medicine, pharmacy, dentistry, and other health professions.

The textbook is divided into six parts. Each part reflects the *Overarching Concepts and Fundamental Statements* found in the American Society for Microbiology **Recommended Curriculum Guidelines for Undergraduate Microbiology Education** as published in the *Journal of Microbiology and Biology Education* (Merkel, *JMBE* May 2012, pp 32-38).

Overarching Concepts and Fundamental Statements[1]	
Evolution	1. Cells, organelles (e.g., mitochondria and chloroplasts), and all major metabolic pathways evolved from early prokaryotic cells. 2. Mutations and horizontal gene transfer, with the immense variety of microenvironments, have selected for a huge diversity of microorganisms. 3. Human impact on the environment influences the evolution of microorganisms (e.g., emerging diseases and the selection of antibiotic resistance). 4. The traditional concept of species is not readily applicable to microbes due to asexual reproduction and the frequent occurrence of horizontal gene transfer. 5. Evolutionary relatedness of organisms is best reflected in phylogenetic trees.
Cell Structure and Function	6. The structure and function of microorganisms have been revealed by the use of microscopy (including bright field, phase contrast, fluorescent, and electron). 7. Bacteria have unique cell structures that can be targets for antibiotics, immunity, and phage infection. 8. Bacteria and Archaea have specialized structures e.g., flagella, endospores, and pili) that often confer critical capabilities. 9. While microscopic eukaryotes (for example, fungi, protozoa and algae) carry out some of the same processes as bacteria, many of the cellular properties are fundamentally different. 10. The replication cycles of viruses (lytic and lysogenic) differ among viruses and are determined by their unique structures and genomes.
Metabolic Pathways	11. Bacteria and Archaea exhibit extensive, and often unique, metabolic diversity (e.g., nitrogen fixation, methane production, anoxygenic photosynthesis). 12. The interactions of microorganisms among themselves and with their environment are determined by their metabolic abilities (e.g., quorum sensing, oxygen consumption, nitrogen transformations). 13. The survival and growth of any microorganism in a given environment depends on its metabolic characteristics. 14. The growth of microorganisms can be controlled by physical, chemical, mechanical, or biological means.
Information Flow and Genetics	15. Genetic variations can impact microbial functions (e.g., in biofilm formation, pathogenicity and drug resistance). 16. Although the central dogma is universal in all cells, the processes of replication, transcription, and translation differ in Bacteria, Archaea, and Eukaryotes. 17. The regulation of gene expression is influenced by external and internal molecular cues and/or signals. 18. The synthesis of viral genetic material and proteins is dependent on host cells. 19. Cell genomes can be manipulated to alter cell function.

Microbial Systems	20. Microorganisms are ubiquitous and live in diverse and dynamic ecosystems. 21. Most bacteria in nature live in biofilm communities. 22. Microorganisms and their environment interact with and modify each other. 23. Microorganisms, cellular and viral, can interact with both human and nonhuman hosts in beneficial, neutral, or detrimental ways.
Impact of Microorganisms	24. Microbes are essential for life, as we know it, and the processes that support life (e.g., in biogeochemical cycles and plant and/or animal microbiota). 25. Microorganisms provide essential models that give us fundamental knowledge about life processes. 26. Humans utilize and harness microorganisms and their products. 27. Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored.

[1]Reproduced from Curriculum Guidelines for Undergraduate Microbiology (September 2014) https://www.asm.org/getattachment/1b074b9e-8522-4d9d-bbc3-c0ca9b9abf1a/FINAL_Curriculum_Guidelines_w_title_page.pdf.

What's New in This Edition

When you read this text, you get a global perspective on microbiology and infectious disease as found in no other similar textbook. The current edition has been updated with the latest scientific and education research and has incorporated many suggestions made by my colleagues, by emails received from microbiology instructors, and by my students and other students around the world. Along with these revisions, the visual aspects of the text have been improved to make the understanding of complex concepts more approachable and the figures more engaging. Each chapter now includes several **SEEING THE CONCEPT** figures that highlight important microbiological concepts. The new **COVID-19 pandemic material** (see table for COVID-19 topics and material) is the single, most extensive addition to the current edition. All the basic and fundamental information is present in context with chapter key concepts.

COVID-19 Topics and Material (by chapter)

Chapter 1	COVID-19 as an emerging disease.
Chapter 6	SARS-CoV-2 as part of virosphere; structure; classification; replication.
Chapter 9	Clinical case.
Chapter 10	SARS-CoV-2 and mutations.
Chapter 13	COVID-19 diagnostic testing.
Chapter 14	Chapter opener; COVID-19 disease description.
Chapter 20	Chapter opener; airborne transmission; zoonotic disease; reservoir and superspreaders; portal of entry; infectious dose; as a primary infection; course of infection; epidemiology; basic reproductive number (R_0); community spread; emerging disease.
Chapters 21 & 22	Cytokine storm; clonal selection; antibody production; as a subclinical disease; vaccine development; active/passive acquired immunity; herd immunity.
Chapter 23	Association with multisystem inflammatory syndrome in children (MIS-C).

New Chapter Content

Each chapter of *Fundamentals of Microbiology, Twelfth Edition* has been carefully and thoroughly edited and revised. New information pertinent to nursing and allied health has been included, while many figures and tables have been updated, revised, and/or reorganized for clarity. Here are the other major changes.

- **Chapter 1** has been reorganized and revised to reflect the role microbes play on a daily basis around the globe as well as within the human body. The emphasis here is to show how important microbes are to daily life beyond the infectious diseases that a limited number of species might cause. In addition, a more concise section on the important pioneers to microbiology is presented along with the place of microbiology today in helping solve many problems of scientific and medical importance.

Part I: Microbial Cell Biology

This part introduces students to the world of microbial cells and viruses, both chemically, globally, and as individual units of life.

- **Chapter 2** still contains the basic chemistry, as much as microbial growth, metabolism, and control are grounded in molecules and macromolecules and in the biological processes these substances undergo.
- **Chapter 3** has revised material on the naming of microbes and the tools (microscopes) needed to observe the tiny organisms. The chapter also has update material on the cataloging of organisms and the organization of these living cells into the tree of life. **Chapter 4** continues to concentrate on the bacterial organisms, where we survey their structural frameworks.

  Previously, the eukaryotic microbes and viruses were covered in later chapters (Chapters 15, 18, and 19 in the previous edition of *Fundamentals*). Now, these organisms and viruses have been brought forward to be covered along with and compared to the bacterial organisms. In **Chapter 5**, a discussion similar to that in Chapter 4 focuses on the protists, fungi, and the multicellular animal parasites, the helminths. Part I concludes with **Chapter 6**, which describes the viruses, those microbial agents that are of great significance to all organisms, including humans.

  Together, Chapters 3 through 6 now provide an integrated set of chapters describing the agents comprising the microbial world. The information of infectious diseases caused by these microbes, worms, and viruses has been moved to the appropriate chapter in Part IV (Microbial and Viral Diseases of Humans).

Part II: Microbial Growth, Metabolism, and Genetics

Part II covers an important aspect of microbiology that some students might find more difficult in comprehending its importance, especially to the nursing and allied health fields. Practicing nurses often lack the understating and skill using genetics and genomic technologies when dealing with patient care. Therefore, these chapters have been revised to enhance the integration of genetic and genomic content that future nurses and allied health students will need in their careers and health care practices.

- Chapters 7 through 10 cover the important material on the growth and metabolism of microorganisms, as well as information on genetics, genetic engineering, and microbial genomics and biotechnology. In **Chapter 7**, the frameworks used to examine microbial growth patterns and nutritional requirements have been simplified. **Chapter 8** describes the metabolism of microbial cells, including those chemical reactions that produce energy and use energy. Again, the figures and narrative have been clarified and simplified.
- The contributions of microbial genetics have been numerous, diverse, and far-reaching. Today, genomic analyses of microorganisms have broad significance not only for microbiology, human health, industry, and the environment, but also in our daily lives.

  Chapter 9 is devoted to the basics of microbial genetics. We examine how microbial DNA is replicated and how this information codes for and directs protein synthesis. Added attention has been given to visualizing concepts, which make the material easier to understand and learn. **Chapter 10** introduces the fields of genetic engineering, biotechnology, and microbial genomics, areas that today are playing a bigger part in health care. Again, making concepts, such as horizontal gene transfer and unique techniques of genetic engineering, more visual has been a major emphasis in the revision of this chapter.

Part III: Control of Microorganisms

Part III covers the physical methods and chemical agents used to control microbial growth and the antimicrobial drugs used to cure or control infectious diseases.

- **Chapter 11** considers the physical methods and chemical agents. Other than reviewing these pages, there were no major changes in content in this chapter. **Chapter 12** is an important chapter on antimicrobial drugs and antimicrobial resistance. The material has been updated with the current understanding of antimicrobial resistance, especially with regard to antibiotic resistance. Figures have been revised to illustrate clearly how resistance develops and the discussion of origins of resistance have been reorganized.

Part IV: Microbial and Viral Diseases of Humans

In Part IV, the infectious diseases of the human body are surveyed.

- ***NEW* Chapter 13** focuses on how diseases are diagnosed. It includes new material on the methods used to identify and diagnose an infection and the need for clinical specimens that are of high quality for testing. The rest of the chapter examines methods and tests for diagnosis. This includes phenotypic methods (microscopy, staining, and biochemical testing), nucleic acid–based methods involving nucleic acid sequencing, and serological tests. The latter is the material that was in Chapter 23 of the previous edition.
- In these following six chapters (**Chapters 14 through 19**), the various infectious diseases are discussed according to the body system typically colonized by the infectious agent. In each of the body system chapters, the infectious diseases have been reorganized and the pertinent information presented in the following sequence:
    - Epidemiology
    - Infectious Agent and Transmission
    - Clinical Presentation and Diagnosis
    - Treatment and Prevention

Part V: Interactions and Impact of Microorganisms with Humans

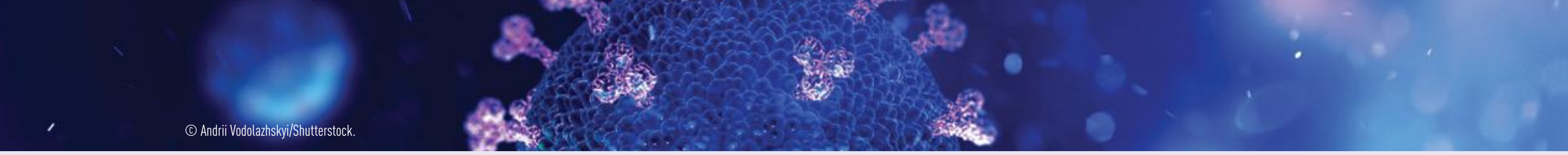
In Part V of this text, we explore the infectious disease process and the mechanisms by which the body responds to disease. The decision was made to place immunology after the discussion of infectious diseases, although the chapters on immunology could certainly be discussed in class prior to the diseases. The rational for discussing the immune response to infection after infectious diseases is that knowing the behaviors and virulence factors of microbes makes it clear how the immune system works to control and hopefully defeat these infectious agents.

- **Chapter 20** is an overview of the host–microbe relationship and the factors contributing to the establishment of disease. Within this chapter, the material on epidemiology has been completely revised, based on the recent events with COVID-19. This portion of the chapter emphasizes descriptive epidemiology, how epidemiologists track infectious diseases, how epidemic curves are generated, and the basics for carrying out an epidemiological investigation. Much of the information uses COVID-19 as the example disease.
- **Chapter 21** now is organized into surface barriers and nonspecific (innate) immunity. **Chapter 22** continues the discussion with specific (adaptive) immunity methods by which the body develops resistance to a particular pathogen. Added to this chapter is the material on vaccinations and immunizations. This was previously in Chapter 23 along with serology, the latter now moved to Chapter 13. In **Chapter 23** the discussion centers on immune disorders and immune deficiencies leading to serious problems in humans. The material on AIDS can now be found much earlier in the text in the chapter on Systemic Infectious Diseases.

Part VI: Applied and Environmental Microbiology

The last part of the text turns to the more applied (industrial) and environmental aspects of microbiology. These chapters, only available online, remain essentially the same (with some figure changes) from the previous edition.

- **Chapter 24** on applied and industrial microbiology is organized around food spoilage, food preservation, and industrial uses of microbes in food production (fermentation).
- **Chapter 25** covers important aspects of environmental microbiology, including the biogeochemical cycles.



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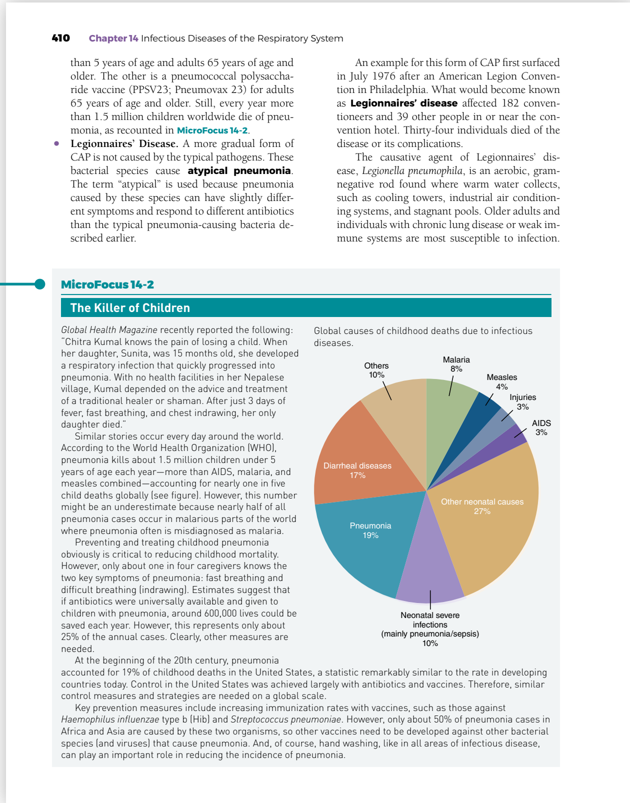
The Student Experience

A Global Perspective

Many decades ago, nursing and allied health students studying microbiology only needed to be concerned about infectious diseases as related to their community or geographic region. Today, with global travel, diseases from halfway around the world can be at our doorstep almost overnight. COVID-19 is an excellent example. Therefore, students need a more global perspective of infectious disease and an understanding and familiarity with these diseases, which are presented no better than in this text.

MICROFOCUS features provide students with the information and understanding they need. Each article, such as the one about childhood pneumonia, provides the background and significance needed for students to be informed and conversant.



410 **Chapter 14** Infectious Diseases of the Respiratory System

than 5 years of age and adults 65 years of age and older. The other is a pneumococcal polysaccharide vaccine (PPSV23; Pneumovax 23) for adults 65 years of age and older. Still, every year more than 1.5 million children worldwide die of pneumonia, as recounted in **MicroFocus 14-2**.

- **Legionnaires' Disease.** A more gradual form of CAP is not caused by the typical pathogens. These bacterial species cause **atypical pneumonia**. The term "atypical" is used because pneumonia caused by these species can have slightly different symptoms and respond to different antibiotics than the typical pneumonia-causing bacteria described earlier.

An example for this form of CAP first surfaced in July 1976 after an American Legion Convention in Philadelphia. What would become known as **Legionnaires' disease** affected 182 conventioneers and 39 other people in or near the convention hotel. Thirty-four individuals died of the disease or its complications.

The causative agent of Legionnaires' disease, *Legionella pneumophila*, is an aerobic, gram-negative rod found where warm water collects, such as cooling towers, industrial air conditioning systems, and stagnant pools. Older adults and individuals with chronic lung disease or weak immune systems are most susceptible to infection.

MicroFocus 14-2

The Killer of Children

Global Health Magazine recently reported the following: "Chitra Kumal knows the pain of losing a child. When her daughter, Sunita, was 15 months old, she developed a respiratory infection that quickly progressed into pneumonia. With no health facilities in her Nepalese village, Kumal depended on the advice and treatment of a traditional healer or shaman. After just 3 days of fever, fast breathing, and chest indrawing, her only daughter died."

Similar stories occur every day around the world. According to the World Health Organization (WHO), pneumonia kills about 1.5 million children under 5 years of age each year—more than AIDS, malaria, and measles combined—accounting for nearly one in five child deaths globally (see figure). However, this number might be an underestimate because nearly half of all pneumonia cases occur in malarious parts of the world where pneumonia often is misdiagnosed as malaria.

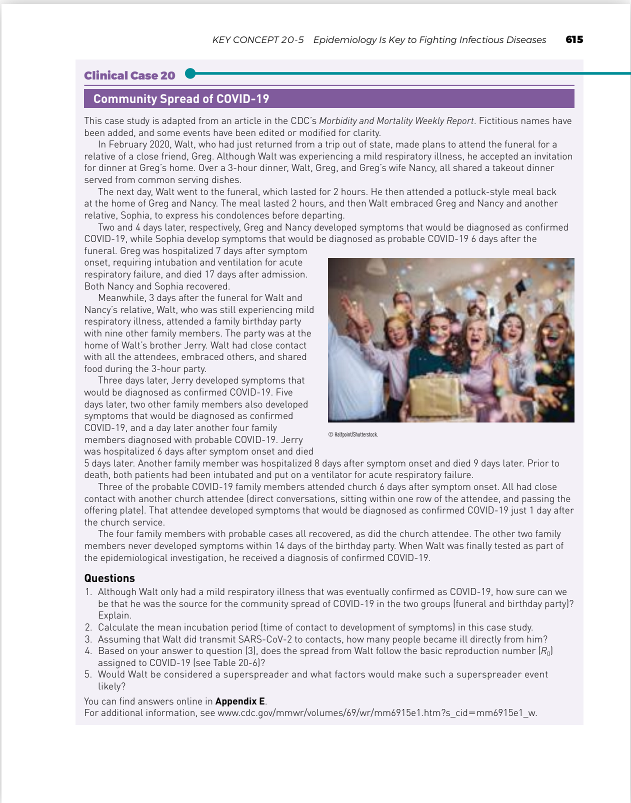
Preventing and treating childhood pneumonia obviously is critical to reducing childhood mortality. However, only about one in four caregivers knows the two key symptoms of pneumonia: fast breathing and difficult breathing (indrawing). Estimates suggest that if antibiotics were universally available and given to children with pneumonia, around 600,000 lives could be saved each year. However, this represents only about 25% of the annual cases. Clearly, other measures are needed.

Global causes of childhood deaths due to infectious diseases.

At the beginning of the 20th century, pneumonia accounted for 19% of childhood deaths in the United States, a statistic remarkably similar to the rate in developing countries today. Control in the United States was achieved largely with antibiotics and vaccines. Therefore, similar control measures and strategies are needed on a global scale.

Key prevention measures include increasing immunization rates with vaccines, such as those against *Haemophilus influenzae* type b (Hib) and *Streptococcus pneumoniae*. However, only about 50% of pneumonia cases in Africa and Asia are caused by these two organisms, so other vaccines need to be developed against other bacterial species (and viruses) that cause pneumonia. And, of course, hand washing, like in all areas of infectious disease, can play an important role in reducing the incidence of pneumonia.

CLINICAL CASES also provide the opportunity to develop a working knowledge of microbial infections that is essential for student achievement and career success. These cases often are presented as a series of disease observations that are accompanied by several questions to develop the student's thinking skills.



KEY CONCEPT 20-5 Epidemiology Is Key to Fighting Infectious Diseases **615**

Clinical Case 20

Community Spread of COVID-19

This case study is adapted from an article in the CDC's *Morbidity and Mortality Weekly Report*. Fictitious names have been added, and some events have been edited or modified for clarity.

In February 2020, Walt, who had just returned from a trip out of state, made plans to attend the funeral for a relative of a close friend, Greg. Although Walt was experiencing a mild respiratory illness, he accepted an invitation for dinner at Greg's home. Over a 3-hour dinner, Walt, Greg, and Greg's wife Nancy, all shared a takeout dinner served from common serving dishes.

The next day, Walt went to the funeral, which lasted for 2 hours. He then attended a potluck-style meal back at the home of Greg and Nancy. The meal lasted 2 hours, and then Walt embraced Greg and Nancy and another relative, Sophia, to express his condolences before departing.

Two and 4 days later, respectively, Greg and Nancy developed symptoms that would be diagnosed as confirmed COVID-19, while Sophia develop symptoms that would be diagnosed as probable COVID-19 6 days after the funeral. Greg was hospitalized 7 days after symptom onset, requiring intubation and ventilation for acute respiratory failure, and died 17 days after admission. Both Nancy and Sophia recovered.

Meanwhile, 3 days after the funeral for Walt and Nancy's relative, Walt, who was still experiencing mild respiratory illness, attended a family birthday party with nine other family members. The party was at the home of Walt's brother Jerry. Walt had close contact with all the attendees, embraced others, and shared food during the 3-hour party.

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Three days later, Jerry developed symptoms that would be diagnosed as confirmed COVID-19. Five days later, two other family members also developed symptoms that would be diagnosed as confirmed COVID-19, and a day later another four family members diagnosed with probable COVID-19. Jerry was hospitalized 6 days after symptom onset and died 5 days later. Another family member was hospitalized 8 days after symptom onset and died 9 days later. Prior to death, both patients had been intubated and put on a ventilator for acute respiratory failure.

Three of the probable COVID-19 family members attended church 6 days after symptom onset. All had close contact with another church attendee (direct conversations, sitting within one row of the attendee, and passing the offering plate). That attendee developed symptoms that would be diagnosed as confirmed COVID-19 just 1 day after the church service.

The four family members with probable cases all recovered, as did the church attendee. The other two family members never developed symptoms within 14 days of the birthday party. When Walt was finally tested as part of the epidemiological investigation, he received a diagnosis of confirmed COVID-19.

Questions

1. Although Walt only had a mild respiratory illness that was eventually confirmed as COVID-19, how sure can we be that he was the source for the community spread of COVID-19 in the two groups (funeral and birthday party)? Explain.
2. Calculate the mean incubation period (time of contact to development of symptoms) in this case study.
3. Assuming that Walt did transmit SARS-CoV-2 to contacts, how many people became ill directly from him?
4. Based on your answer to question (3), does the spread from Walt follow the basic reproduction number (R_0) assigned to COVID-19 (see Table 20-6)?
5. Would Walt be considered a superspreader and what factors would make such a superspreader event likely?

You can find answers online in **Appendix E**.
For additional information, see www.cdc.gov/mmwr/volumes/69/wr/mm6915e1.htm?s_cid=mm6915e1_w.

INVESTIGATING THE MICROBIAL WORLD (IMW) introduces students to real world science. Although most students will not be entering the research field, the nursing and allied health arenas require that they have a familiarity with how science is done. The examples in each chapter vary from basic to applied science experiments and, as in the IMW on antibiotic resistance, often have real world (and personal) implications.

One of the best ways to ensure mastery of a topic is through further thought and conversation. Again, the application to what a student has read will not only indicate if she or he has mastered the material, but also strengthen her or his critical-thinking skills.

KEY CONCEPT 12-7 *Antimicrobial Drug Resistance Is a Growing Challenge* **353**

antimicrobials. Unfortunately, many microbes and pathogens have continued to become resistant to these drugs. Yet, despite this increase in AMR, the development of new antimicrobial agents is failing in a time when there is a pressing need for these drugs. Fortunately, there has been a slight upsurge in antibiotic approvals in the last few years.

One reason the pharmaceutical industry has lagged behind in developing and bringing new antimicrobial drugs to market is the high cost of drug

Investigating the Microbial World 12

The Source of Antibiotic Resistance

Following the discovery and development of the first antibiotics for clinical use in the 1940s, it did not take many bacterial species long to express antibiotic resistance. But did the development and use of antibiotics in medicine produce the "driving force" for bacterial species to evolve and spread resistance genes that then transformed much of the natural microbiota? Alternatively, is resistance an ancient phenomenon that spread from the natural microbiota to clinically important pathogenic species?

Observations: Some surveys comparing soil samples from the pre-antibiotic era (~1940) with contemporary soil samples report that the relative abundance of antibiotic resistance genes has increased in contemporary soils. Such surveys suggest resistance genes are modern evolutionary consequences of antibiotic development and use. Other investigations analyzing microbial DNA sequences from Pleistocene permafrost sediments (dated to be 30,000 years old) report the identification of resistance genes to many different classes of antibiotics. These investigations suggest that antibiotic resistance is quite ancient, reflecting a rich and diverse reservoir of resistance genes.

Question: *Is the presence of resistance genes in microbes the result of contemporary development and use of antibiotics?*

Hypothesis: Antibiotic resistance is prevalent in microbial populations that have been isolated from contact with human sources of antibiotics. If so, investigating an environment that has never been exposed to contemporary antibiotics should result in finding resistance genes among the environment's microbiomes.

Experimental site and design: A region of Lechuguilla Cave, located in Carlsbad Caverns National Park, New Mexico, was selected for study. The cave is 300 to 400 meters below the surface and is believed to have been isolated from surface water and human exposure for more than 4 million years. Of the 500 unique bacterial isolates collected from three deep, remote sample sites in the cave (see Figure A), 93 grew readily in tryptic soy broth. Ribosomal RNA gene sequencing classified 33% as gram-positive and 63% as gram-negative genera.

Experiment: To determine if any of the 93 strains contained antibiotic resistance, each was tested for growth in the presence and absence of up to 26 different antibiotics (20 μg/mL), representing natural, semisynthetic, and synthetic drugs.

Results: See Figure B.

Questions

1. ***From Figure B, do the antibiotics used in this study target the diverse bacterial cell structures and processes that are potentially susceptible to antibiotics? Explain. (Also refer to Figure 12-9.)***
2. ***Daptomycin is a new class of antibiotics that was approved for clinical use in the late 1980s. Is it surprising that almost 20% of the gram-positive isolates (see Figure B) are resistant to this drug?***
3. ***Does this finding favor the idea that antibiotic resistance is ancient? Explain.***
4. ***Is the hypothesis supported? Explain.***

You can find answers online in **Appendix E**.

Figure A Lechuguilla Cave

Courtesy of Max Wisshak www.speleo-foto.de.

(continues)

4 **Chapter 1** Introduction to Microbiology: Then and Now

KEY CONCEPT 1-1 Microbial Communities Support and Affect All Life on Earth

Almost 4 billion years ago, Earth was a microbial planet. The diverse and numerous microorganisms populating the planet were beginning the processes that would create the environment that sustains and shapes our planet and that has made Earth habitable no less impressive in its daily activities than that of its marine counterparts. In fact, every time you walk on the soil, you step on billions of microbes (**Figure 1-3**). Moreover, like their cousins in the oceans, they are found in every imaginable environment, from the tops

KEY CONCEPT organization presents section statements identifying the important concepts in the upcoming section and alerts you to the significance of that written material.

CHAPTER SELF-TEST organization outlines the important concepts in the chapters through Bloom's Taxonomy, which is a classification of levels of intellectual skills important in learning. The three steps for the self-tests are:

- **STEP A: Recall** are multiple-choice, matching, and true–false questions focusing on concrete "facts" learned in the chapter. Let's face it; there is information that needs to be memorized in order to reason critically.
- **STEP B: Application and Analysis** are questions requiring students to analyze and reason critically through a problem of practical significance.
- **STEP C: Evaluation and Discussion** encourage students to use the text to resolve thought-provoking problems with contemporary relevance.

Chapter Self-Test

For more practice quizzes, assessments, animations, videos, and other study aids, go online to **NAVIGATE 2**.

For **Steps A–C**, you can find answers to questions and problems in **Appendix F**.

STEP A: Recall

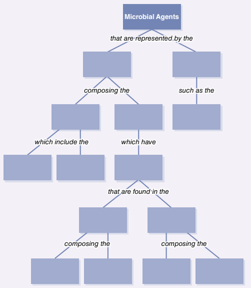
Read each question or statement carefully before selecting an answer.

1. Define microbiome.
2. Which part of the human body is home to the greatest number of bacteria?
3. Who was the first person to see bacterial cells with a microscope?
   A. Pasteur
   B. Koch
   C. Leeuwenhoek
   D. Hooke

STEP B: Application and Analysis

9–12. Which of the following statements are **true** (**T**) and which are **false** (**F**)? If the statement is false, substitute a word or phrase for the underlined word or phrase to make the statement true.

9. _____ Leeuwenhoek believed that animalcules caused anthrax.
10. _____ Pasteur proposed the germ theory.
11. _____ Viruses must infect other cells to replicate.
12. _____ When talking about antibiotic resistance, "resistance" refers to the human body not responding to the antibiotic.
13. Complete the concept map for **Microbial Agents** on the right by using the following terms to fill in the empty boxes. Each term should be used only once.
    - Algae
    - Archaeal cells
    - Bacterial cells
    - Cellular agents
    - Eukaryotes
    - Fungi
    - Molds
    - Noncellular agents
    - Nucleated cells
    - Prokaryotes
    - Protists
    - Protozoa
    - Viruses
    - Yeasts
14. You discover a new species of microbe growing in the soil. How would you determine if the microbe is a prokaryotic or eukaryotic cell? Suppose that it is a eukaryote. What information would be needed to determine if it is a member of the protists or a member of the fungi?
15. As microbiologists continue to explore the microbial universe, it is becoming more apparent that microbes are "invisible emperors" that rule the world. Now that you have completed this chapter, provide three examples to support the statement: *Microbes rule!*



24 **Chapter 1** Introduction to Microbiology: Then and Now

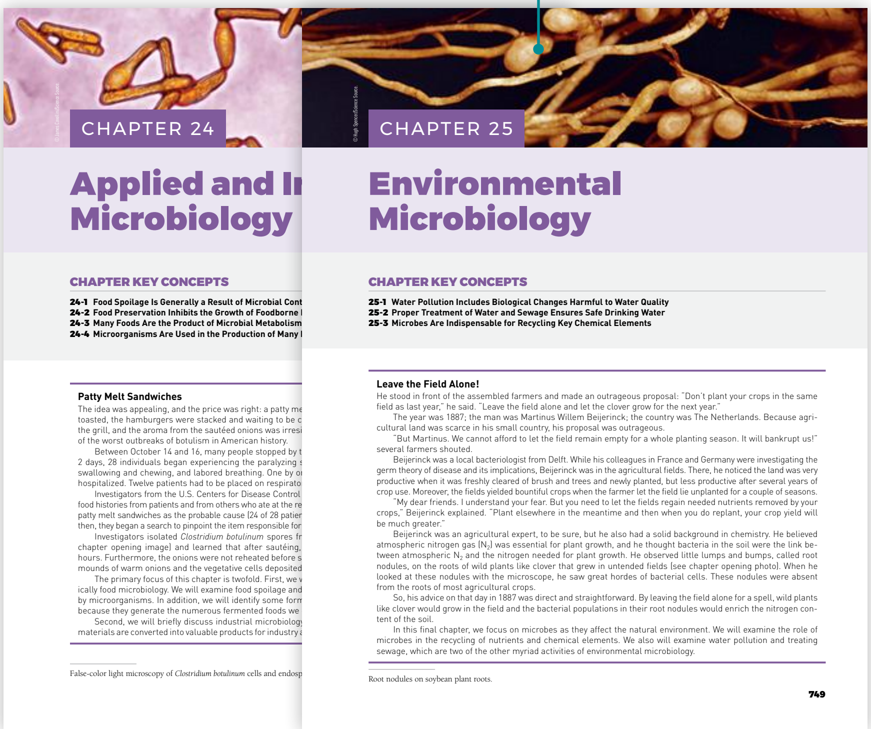
STEP C: Evaluation and Discussion

16. Can you think of an environment on Earth where microbes would not be found naturally?
17. Judge the importance of (a) the germ theory of disease and (b) Koch's postulates to the identification of microbes as agents of infectious disease.
18. Louis Pasteur once stated, "Life [plant and animal] would not long remain possible in the absence of microbes." From your reading about microbiomes, why might plant and animal life suffer without microbes?
19. When you tell a friend that you are taking microbiology this semester, she asks, "Exactly what is microbiology?" How do you answer her?
20. Who would you select as the "first microbiologist"? (a) Leeuwenhoek? (b) Hooke? (c) Pasteur and Koch? Support your decision.

Jones & Bartlett Learning offers an assortment of supplements to assist students in mastering the concepts in this text.

Animations: Engaging animations bring fascinating microbiology phenomena to life! Each animation guides students through microbiology processes and gauges students' progress and understanding with exercises and assessment questions introduced throughout each narrated animation.

Bonus eBook content: Two bonus chapters, "Applied and Industrial Microbiology" and "Environmental Microbiology," are available online.



CHAPTER 24

CHAPTER 25

Environmental Microbiology

CHAPTER KEY CONCEPTS

25-1 Water Pollution Includes Biological Changes Harmful to Water Quality
25-2 Proper Treatment of Water and Sewage Ensures Safe Drinking Water
25-3 Microbes Are Indispensable for Recycling Key Chemical Elements

Leave the Field Alone!

He stood in front of the assembled farmers and made an outrageous proposal: "Don't plant your crops in the same field as last year," he said. "Leave the field alone and let the clover grow for the next year."

The year was 1887; the man was Martinus Willem Beijerinck; the country was The Netherlands. Because agricultural land was scarce in his small country, his proposal was outrageous.

"But Martinus. We cannot afford to let the field remain empty for a whole planting season. It will bankrupt us!" several farmers shouted.

Beijerinck was a local bacteriologist from Delft. While his colleagues in France and Germany were investigating the germ theory of disease and its implications, Beijerinck was in the agricultural fields. There, he noticed the land was very productive when it was freshly cleared of brush and trees and newly planted, but less productive after several years of crop use. Moreover, the fields yielded bountiful crops when the farmer let the field lie unplanted for a couple of seasons.

"My dear friends. I understand your fear. But you need to let the fields regain needed nutrients removed by your crops," Beijerinck explained. "Plant elsewhere in the meantime and then when you do replant, your crop yield will be much greater."

Beijerinck was an agricultural expert, to be sure, but he also had a solid background in chemistry. He believed atmospheric nitrogen gas (N_2) was essential for plant growth, and he thought bacteria in the soil were the link between atmospheric N_2 and the nitrogen needed for plant growth. He observed little lumps and bumps, called root nodules, on the roots of wild plants like clover that grew in untended fields (see chapter opening photo). When he looked at these nodules with the microscope, he saw great hordes of bacterial cells. These nodules were absent from the roots of most agricultural crops.

So, his advice on that day in 1887 was direct and straightforward. By leaving the field alone for a spell, wild plants like clover would grow in the field and the bacterial populations in their root nodules would enrich the nitrogen content of the soil.

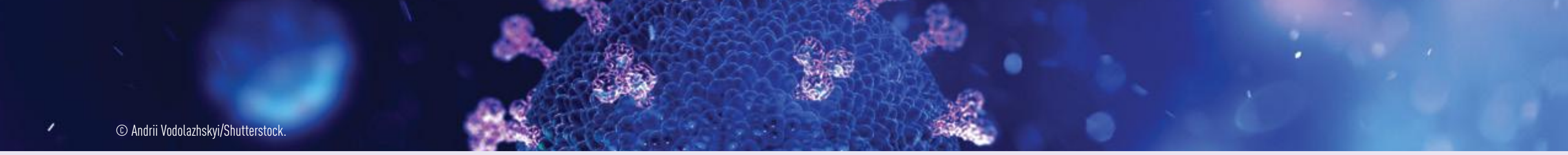
In this final chapter, we focus on microbes as they affect the natural environment. We will examine the role of microbes in the recycling of nutrients and chemical elements. We also will examine water pollution and treating sewage, which are two of the other myriad activities of environmental microbiology.

Root nodules on soybean plant roots.

749

Web Links: A variety of weblinks are available that present external website resources to continue your study of microbiology and keep up to date on what is happening in the field today.

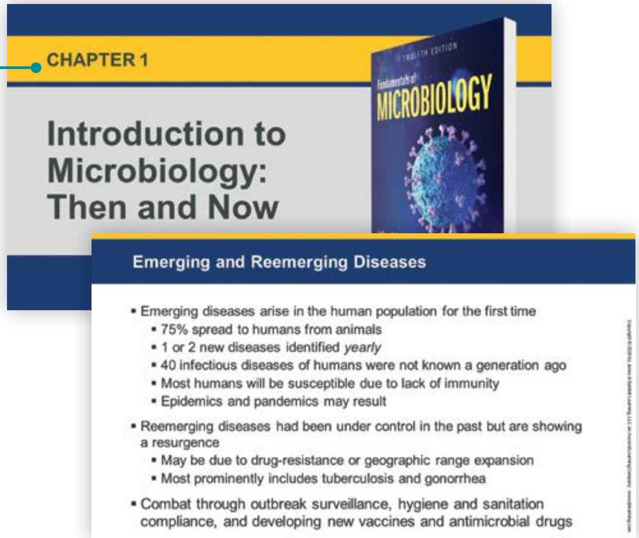
Answer Key: Answers for the end-of-chapter Questions, as well as the questions in the MicroFocus, Chapter Challenge, Clinical Case, and Investigating the Microbial World feature boxes are available in the online Appendices D, E, and F (accessible with access card).



Teaching Tools

Jones & Bartlett Learning also has an array of supportive materials for instructors. Additional information and review copies of any of the following items are available through your Jones & Bartlett Learning sales representative or by going to http://www.jblearning.com.

The **PowerPoint Lecture Outline** presentation package provides lecture notes and images for each chapter of the text. Instructors with Microsoft PowerPoint software can customize the outlines, art, and order of presentation.



The **Image Bank in PowerPoint format** provides images of the illustrations, photographs, and tables (to which Jones & Bartlett Learning holds the copyright or has permission to reproduce digitally). These images are not for sale or distribution, but you can copy individual images or tables into your existing lecture presentations, test and quizzes, or other classroom materials.

An **Unlabeled Art Image Bank in PowerPoint format** provides selected images from the text with the labels removed so you can easily integrate them into your lectures, assignments, or exams.

The **Instructor's Manual**, provided as a text file, includes an Instructional Overview, Instructional Objectives, Key Terms and Concepts, Chapter Teaching Points and Tips, and Essay Questions.

A robust **Test Bank**, including hundreds of assessment questions, is available.

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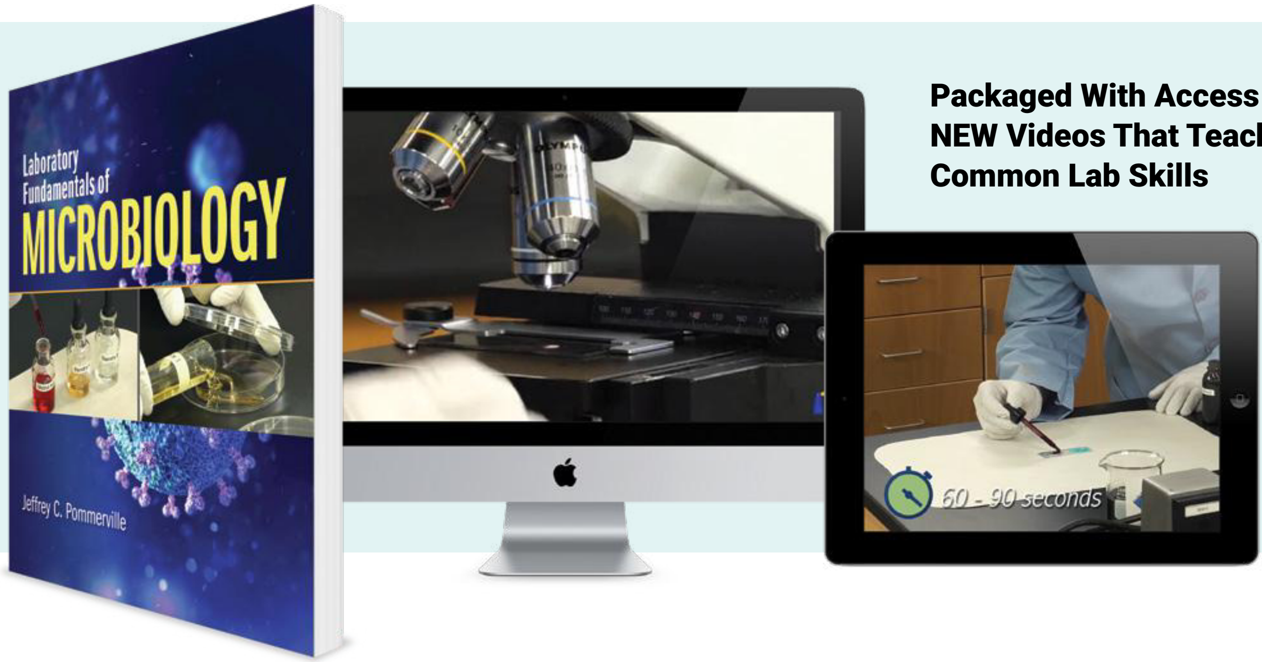

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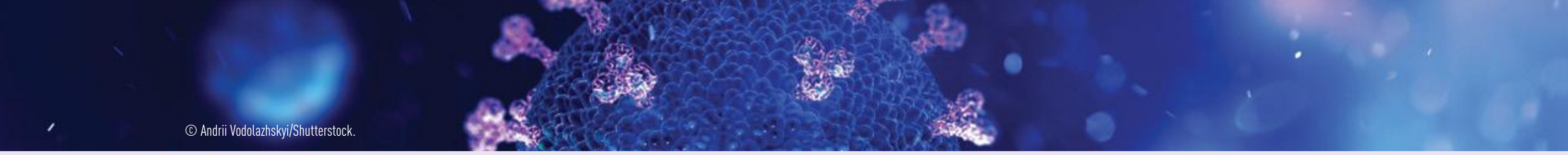
Section: Medical Microbiology
Preparing the Acid-Fast Stain
Oxidase Test
IMViC: Indole Test
IMViC: Methyl Red Test
IMViC: Voges-Proskauer Test
IMViC: Citrate Test

Section: Identification of a Bacterial Unknown
Biochemical Tests: Carbohydrate Fermentation
Starch Hydrolysis Test
Catalase Test
Hydrogen Sulfate
Urease Test

Visit **go.jblearning.com/PommervilleLabVideos** to view a sample video

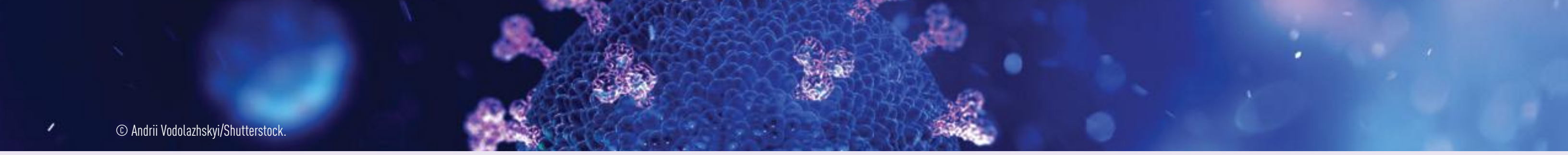


Acknowledgments

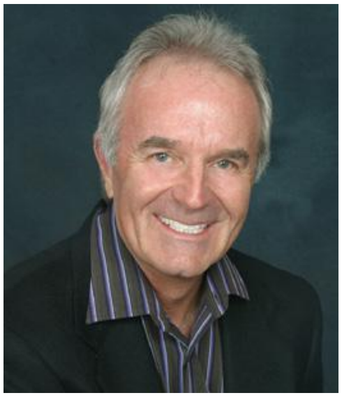
Textbook revisions are always a major project and a team effort. The new edition of *Fundamentals of Microbiology* is no exception. Moreover, when the team members at Jones & Bartlett Learning are exceptionally talented professionals, my work is made easier. That is especially true as this edition was done more remotely than any previous edition. I wish to thank Melissa Duffy, Content Strategist, who coordinated the textbook revision with skill and direction. I also want to thank Alex Schab for all his help and guidance during the production process.

Throughout all my years of teaching at universities and colleges, I have had great fortune of working with great colleagues and outstanding students. My students kept me on my toes in the classroom, required me to always be prepared, and let me know when a topic or concept was not conveyed in as clear and understandable a way as it could (or should) be. Their suggestions and evaluations encouraged me to continually assess my instruction and make it the best it could be. I salute all my former students—and I hope those of you who read this text will let me know what works and what still needs improvement to make your learning effective, enjoyable, and most of all—successful.

Jeff Pommerville, PhD
Professor Emeritus
Glendale Community College
Glendale, AZ



About the Author



Today, I am a microbiologist, researcher, and science educator. My plans did not start with that intent. While in high school in Santa Barbara, California, I wanted to play professional baseball, study the stars, and own a '66 Corvette. None of those desires would come true—as a high school baseball player my batting average was miserable (but I was a good defensive fielder), I hated the astronomy correspondence course I took in high school, and I never bought that Corvette.

I found an interest in biology at Santa Barbara City College. After squeaking through college calculus, I transferred to the University of California at Santa Barbara (UCSB) where I received a B.S. in biology and stayed on to pursue a Ph.D. in the lab of the late Ian Ross studying cell communication and sexual pheromones in a water mold. After receiving my doctorate in cell and organismal biology, my graduation was written up in the local newspaper as a native son who was a fungal sex biologist—an image that was not lost on my three older brothers!

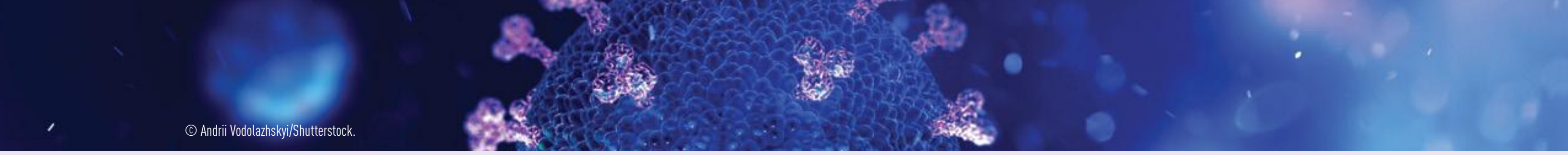
While in graduate school at UCSB, I rescued a secretary in distress from being licked to death by a German shepherd. Within a year, we were married (the secretary and I). When I finished my doctoral thesis, I spent several years as a postdoctoral fellow at the University of Georgia. Worried that I was involved in too many research projects, a faculty member told me something I will never forget. He said, "Jeff, it's when you can't think of a project or what to do that you need to worry." Well, I have never had to worry!

Moving to Texas A&M University, I spent 8 years in teaching and research—and telling Aggie jokes. Toward the end of this time, I realized I had a real interest in teaching and education. Leaving the sex biologist nomen behind, I headed farther west to Arizona to join the biology faculty at Glendale Community College, where I continued to teach introductory biology and microbiology until my retirement in 2018.

I have been lucky to be part of several educational research projects. I was project director and lead principal investigator for a National Science Foundation grant to improve student outcomes in science through changes in curriculum and pedagogy. This culminated in my being honored with the Gustav Ohaus Award (College Division) for Innovations in Science Teaching from the National Science Teachers Association.

For 6 years I was the Perspectives Editor for the *Journal of Microbiology and Biology Education*, the education research journal of the American Society for Microbiology (ASM). I have been cochair for the ASM Conference for Undergraduate Educators and chair of the Undergraduate Education Division of ASM. My dedication to teaching and mentoring students has been recognized by an Outstanding Instructor Award at Glendale Community College and, nationally, the Carski Foundation Distinguished Undergraduate Teaching Award for distinguished teaching of microbiology to undergraduate students and encouraging them to subsequent achievement.

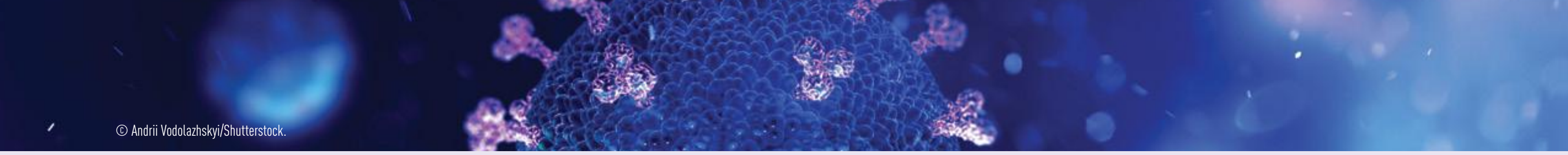
I mention all this not to impress, but to show how the road of life sometimes offers opportunities in unexpected and unplanned ways. The key though is keeping your "hands on the wheel and your eyes on the prize;" then unlimited opportunities will come your way. And, hey, who knows—maybe that '66 Corvette could be in my garage yet.



Dedication

I dedicate this *Twelfth Edition* of the textbook to the two people who most influenced my life in science. My thesis advisor, Ian K. Ross passed away in 2019. He was my mentor and thesis advisor in the early 1970s and in whose lab I was a graduate student for 5 years. He provided the foundation for my scientific thought and excited my interest in the biological sciences that I carried throughout my career.

This is the sixth edition of *Fundamentals of Microbiology* that I have authored. Over these 20 years, I have spent countless months (years?) revising and updating the various editions, often unintentionally neglecting time that should be spent with my wife, Yvonne. She always has supported my passion for teaching and has encouraged me to push forward throughout the textbook revisions, often providing valuable and constructive suggestions. Thanks for your support and encouragement, and enduring love through the years.



Reviewers for the Twelfth Edition

As always, it is the input, suggestions, and comments from instructors and students alike, that evolve a textbook and make each edition an improvement on its predecessor. I thank everyone from previous editions as well as the reviewers for this edition for their time and effort with the review.

Mari Aanenson, MS
Western Illinois University

Vasanta Lakshmi Chivukula, PhD
Atlanta Metropolitan State College

Heather M. Craig, PhD
Monterey Peninsula College

Eric DeAngelo, BA, MS
Lehigh Carbon Community College

Sanhita Gupta, PhD
Kent State University

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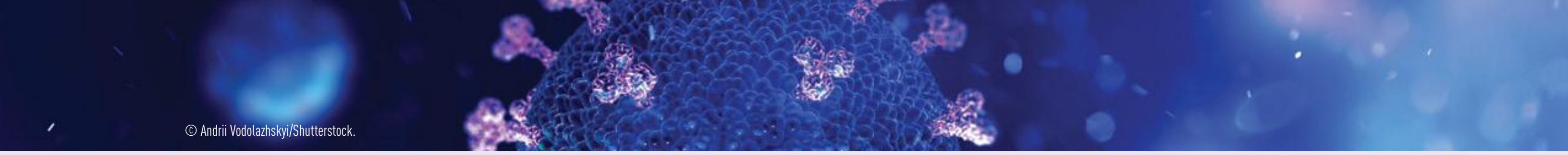


To the Student—Study Smart

Your success in microbiology and any college or university course will depend on your ability to study effectively and efficiently, especially in these times of online learning where more of the responsibility for learning is placed on the student. Therefore, this textbook was designed with you, the student, in mind. The text's organization will help you improve your learning and understanding and, ultimately, your grades. The learning design concept described in the Preface and illustrated below reflects this organization. Study it carefully, and, if you adopt the flow of study shown, you should be a big step ahead in your preparation and understanding of microbiology—and for that matter any subject you are taking.

When I was an undergraduate student, I hardly ever read the "To the Student" section (if indeed one existed) in my textbooks because the section rarely contained any information of importance. This one does, so please read on.

In college, I was a mediocre student until my junior year. Why? Mainly because I did not know how to study properly, and, important here, I did not know how to read a textbook effectively. My textbooks were filled with underlined sentences (highlighters hadn't been invented yet!) without any plan on how I would use this "emphasized" information. In fact, most textbooks assume you know how to read a textbook properly. I didn't, and you might not, either.

Reading a textbook is difficult if you are not properly prepared. So that you can take advantage of what I learned as a student and have learned from instructing thousands of students, I have worked hard to make this text user friendly with a reading style that is not threatening or complicated. Still, there is a substantial amount of information to learn and understand, so having the appropriate reading and comprehension skills is critical. Therefore, I encourage you to spend 30 minutes reading this section, as I am going to give you several tips and suggestions for acquiring those skills. Let me show you how to be an active reader. Note: the Student Study Guide also contains similar information on how to take notes from the text, how to study, how to take class (lecture) notes, how to prepare for and take exams, and perhaps most important for you, how to manage your time effectively. It all is part of this "learning design," my wish to make you a better student.

Be a Prepared Reader

Before you jump into reading a section of a chapter in this text, prepare yourself by finding the place and time and having the tools for study.

Place. Where are you right now as you read these lines? Are you in a quiet library or at home? If at home, are there any distractions, such as loud music, a blaring television, or screaming kids? Is the lighting adequate to read? Are you sitting at a desk or lounging on the living room sofa? Get where I am going? When you read for an educational purpose—that is, to learn and understand something—you need to maximize the environment for reading. Yes, it should be comfortable but not to the point that you will doze off.

Time. All of us have different times during the day when we perform some skill, be it exercising or reading, the best. The last thing you want to do is read when you are tired or simply not "in tune" for the job that needs to be done. You cannot learn and understand the information if you fall asleep or lack a positive attitude. I have kept the chapters in this text to about the same length so you can estimate the time necessary for each and plan your reading accordingly. If you have done your preliminary survey of the chapter or chapter section, you can determine about how much time you will need. If 40 minutes is needed to read—and comprehend (see below)—a section of a chapter, find the place and time that will give you 40 minutes of uninterrupted study. Brain research suggests that most people's brains cannot spend more than 45 minutes in concentrated, technical reading.

Therefore, I have avoided lengthy presentations and instead have focused on smaller sections, each with its own heading. These should accommodate shorter reading periods.

Reading Tools. Lastly, as you read this, what study tools do you have at your side? Do you have a highlighter or pen for emphasizing or underlining important words or phrases? Notice, the text has wide margins, which allow you to make notes or to indicate something that needs further clarification. Do you have a pencil or pen handy to make these notes? Or, if you do not want to "deface" the text, make your notes in a notebook. Lastly, some students find having a ruler is useful to prevent your eyes from wandering on the page and to read each line without distraction.

Be an Explorer Before You Read

When you sit down to read a section of a chapter, do some preliminary exploring. Look at the section head and subheadings to get an idea of what is discussed. Preview any diagrams, photographs, tables, graphs, or other visuals used. They give you a better idea of what is going to occur. We have used a good deal of space in the text for these features, so use them to your advantage. They will help you learn the written information and comprehend its meaning. Do not try to understand all the visuals but try to generate a mental "big picture" of what is to come. Familiarize yourself with any symbols or technical jargon that might be used in the visuals.

The end of each chapter contains a **Summary of Key Concepts** for that chapter. It is a good idea to read the summary before delving into the chapter. That way you will have a framework for the chapter before filling in the nitty-gritty information.

Be a Detective as You Read

Reading a section of a textbook is not the same as reading a novel. With a textbook, you need to uncover the important information (the terms and concepts) from the forest of words on the page. So, the first thing to do is read the complete paragraph. When you have determined the main ideas, highlight or underline them. However, I have seen students highlighting the entire paragraph in yellow, including every a, the, and and. This is an example of highlighting before knowing what is important. So, I have helped you out somewhat. Important terms and concepts are in **bold face** followed by the definition. So only highlight or underline with a pen essential ideas and key phrases—not complete sentences, if possible. By the way, the important microbiological terms and major concepts are also in the **Glossary** at the back of the text.

What if a paragraph or section has no boldfaced words? How do you find what is important here? From an English course, you may know that often the most important information is mentioned first in the paragraph. If it is followed by one or more examples, then you can backtrack and know what was important in the paragraph. In addition, I have added section "speed bumps" (called **Concept Checks**) to let you test your learning and understanding before getting too far ahead in the material. These checks also are clues to what was important in the section you just read.

Be a Repetitious Student

Brain research has shown that each individual can only hold so much information in short-term memory. If you try to hold more, then something else needs to be removed—sort of like a full computer disk. So that you do not lose any of this important information, you need to transfer it to long-term memory—to the hard drive if you will. In reading and studying, this means retaining the term or concept; so, write it out in your notebook using your own words. Memorizing a term does not mean you have learned the term or that you understand the concept. By actively writing it out in your own words, you are forced to think and actively interact with the information. This repetition reinforces your learning.

Be a Patient Student

In textbooks, you cannot read at the speed that you read your email or a magazine story. There are unfamiliar details to be learned and understood—and this requires being a patient, slower reader. Actually, if you are not a fast reader to begin with, as I am, it may be an advantage in your learning process. Identifying the important information from a textbook chapter requires you to slow down your reading speed. Speed-reading is of no value here.

Know the What, Why, and How

Have you ever read something only to say, "I have no idea what I read!" As I've already mentioned, reading a microbiology text is not the same as reading *Sports Illustrated* or *People* magazine. In these entertainment magazines, you read passively for leisure or perhaps amusement. In *Fundamentals of Microbiology, Twelfth*

Edition you must read actively for learning and understanding—that is, for comprehension. This can quickly lead to boredom unless you engage your brain as you read—that is, be an active reader. Do this by knowing the *what, why*, and *how* of your reading.

- *What* is the general topic or idea being discussed? This often is easy to determine because the section heading might tell you. If not, then it will appear in the first sentence or beginning part of the paragraph.
- *Why* is this information important? If I have done my job, the text section will tell you why it is important, or the examples provided will drive the importance home. These surrounding clues further explain why the main idea was important.
- *How* do I "mine" the information presented? This was discussed under being a detective.

A Marked-Up Reading Example

So let's put words into action. Below is a passage from the text. I have marked up the passage as if I were a student reading it for the first time. It uses many of the hints and suggestions I have provided. Remember, it is important to read the passage slowly and concentrate on the main idea (concept) and the special terms that apply.

Nonenveloped Viruses

The simplest animal viruses, such as the polioviruses, consist of just two components: an indispensable nucleic acid core and a surrounding protein shell. Such viruses represent **nonenveloped viruses** (**Figure 6-3A**).

The protein shell, called the **capsid**, surrounds the viral genome while providing shape or symmetry to the particle. The capsid is built from individual protein subunits called **capsomeres** that self-assemble into the virus's shape. On the virus either special capsid proteins called **spikes** or other protein fibers protrude from the surface. These external proteins help attach the virus to protein receptors on, and facilitate entry into, host cells. The capsid also protects the viral nucleic acid against chemical and physical agents and other environmental fluctuations (e.g., temperature and pH changes).

The nucleic acid core, called the **viral genome**, contains one or more molecules of DNA or RNA that have the instructions to make more viruses. The genome can be a double-stranded or a single-stranded form, depending on the specific virus type. Usually the tightly packed nucleic acid is a linear or circular

Have a Debriefing Strategy

After reading the material, be ready to debrief. Verbally summarize what you have learned. This will start moving the short-term information into the long-term memory storage—that is, retention. Any notes you made concerning confusing material should be discussed as soon as possible with your instructor. For microbiology, allow time to draw out diagrams. Again, repetition makes for easier learning and better retention.

In many professions, such as sports or the theater, the name of the game is practice, practice, practice. The hints and suggestions I have given you form a skill that requires practice to perfect and use efficiently. Be patient, things will not happen overnight; perseverance and willingness though will pay off with practice. You might also check with your college or university academic (or learning) resource center. These folks will have more ways to help you to read a textbook better and to study well overall.

Concept Maps

In science as well as in other subjects you take at the college or university, there often are concepts that appear abstract or simply so complex that they are difficult to understand. A concept map is one tool to help you enhance your abilities to think and learn. Critical reasoning and the ability to make connections between complex, nonlinear information are essential to your studies and career.

Concept maps are a learning tool designed to represent complex or abstract information visually. Neurobiologists and psychologists tell us that the brain's primary function is to take incoming information and interpret it in a meaningful or practical way. They also have found that the brain has an easier time making sense of information when it is presented in a visual format. Importantly, concept maps not only present the information in "visual sentences" but also take paragraphs of material and present it in an "at-a-glance" format. Therefore, you can use concept maps to:

- Communicate and organize complex ideas in a meaningful way
- Aid your learning by seeing connections within or between concepts and knowledge
- Assess your understanding or diagnose misunderstanding

- There are many different types of concept maps. The two most used in this textbook are the process map or flow chart and the hierarchical map. The hierarchical map starts with a general concept (the most inclusive word or phrase) at the top of the map and descends downward using more specific, less general words or terms. In several chapters in this textbook process or hierarchical maps are drawn—and you have the opportunity to construct your own hierarchical maps as well.

Concept mapping is the strategy used to produce a concept map. So, let's see how one makes a hierarchical map.

How to Construct a Concept Map

1. Print the central idea (concept or question to be mapped) in a box at the top center of a blank, unlined piece of paper. Use uppercase letters to identify the central idea.
2. Once the concept has been selected, identify the key terms (words or short phrases) that apply to or stem from the concept. Often these may be given to you as a list. If you have read a section of a text, you can extract the terms from that material, as the words are usually boldfaced or italicized.
3. Now, from this list, try to create a hierarchy for the terms you have identified; that is, list them from the most general, most inclusive to the least general, most specific. This ranking may only be approximate and subject to change as you begin mapping.
4. Construct a preliminary concept map. This can be done by writing all of the terms on sticky notes, which can be moved around easily on a large piece of paper. This is necessary as one begins to struggle with the process of building a good hierarchical organization.
5. The concept map connects terms associated with a concept in the following way:
   - The relationship between the concept and the first term(s), and between terms, is connected by an arrow pointing in the direction of the relationship (usually downward or horizontal if connecting related terms).
   - Each arrow should have a label, a very short phrase that explains the relationship with the next term. In the end, each link with a label reads like a sentence.
6. Once you have your map completed, redraw it in a more permanent form. Box in all terms that were on the sticky notes. Remember there may be more than one way to draw a good concept map, and don't be scared off if at first you have some problems mapping; mapping will become more apparent to you after you have practiced this technique a few times using the opportunities given to you in the early chapters of the textbook.
7. Now look at the map and see if it answers the following. Does it:
   - Clearly define the central idea by positioning it in the center of the page?
   - Place all the terms in a logical hierarchy and clearly indicate the relative importance of each term?
   - Allow you to figure out the relationships among the key ideas more easily?
   - Permit you to see all the information visually on one page?
   - Allow you to visualize complex relationships more easily?
   - Make recall and review more efficient?

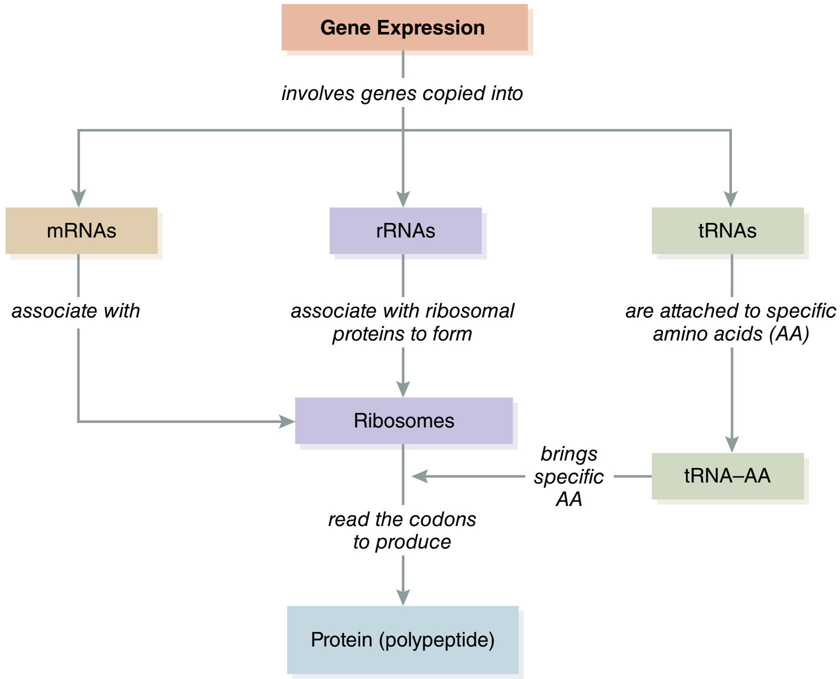
Example

After reading the section on "Gene Expression," a student makes a list of the terms used and maps the concept. Using the steps outlined above, the student produces the following hierarchical map. Does it satisfy all the questions asked in item step 7 above?

Practical Uses for Mapping

- Summarizing textbook readings. Use mapping to summarize a chapter section or a whole chapter in a textbook. This purpose for mapping is used many times in this text.
- Summarizing lectures. Although producing a concept map during the classroom period may not be the best use of the time, making a concept map or maps from the material after class will help you remember the important points and encourage high-level, critical reasoning, which is so important in university and college studies.
- Reviewing for an exam. Having concept maps made ahead of time can be a very useful and productive way to study for an exam, particularly if the emphasis of the course is on understanding and applying abstract, theoretical material, rather than on simply reproducing memorized information.

Figure 9-11 A concept map for gene expression
Gene expression is a combination of the processes of transcription and translation. ***Circle the part of the concept map that represents (a) transcription and (b) translation.***



- Working on an essay. Mapping also is a powerful tool to use during the early stages of writing a course essay or term paper. Making a concept map before you write the first rough draft can help you see and ensure you have the important points and information you will want to make.

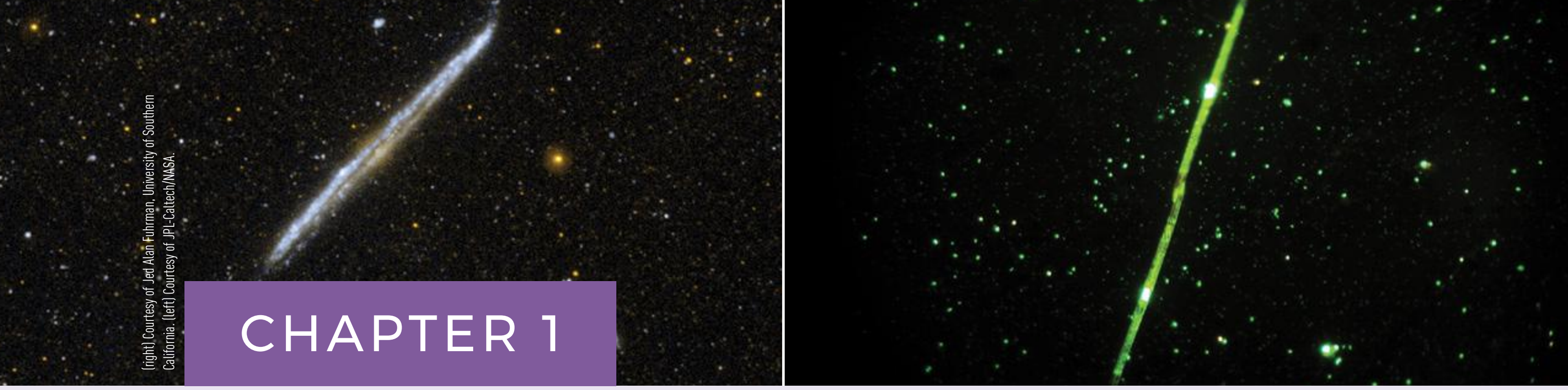
Send Me a Note

In closing, I would like to invite you to email me and let me know what is good about this textbook so I can build on it and what may need improvement so I can revise it. Also, I would be pleased to hear about any news of microbiology in your community, and I'd be happy to help you locate any information not covered in the text.

I wish you great success in your microbiology course. Welcome! Let's now plunge into the wonderful and often awesome world of microorganisms.

—Dr. P

Email: jeffpommervillephd@gmail.com



(right) Courtesy of Jed Alan Fuhrman, University of Southern California. (left) Courtesy of JPL-Caltech/NASA.

CHAPTER 1

Introduction to Microbiology: Then and Now

CHAPTER KEY CONCEPTS

1-1 **Microbial Communities Support and Affect All Life on Earth**
1-2 **The Human Body Has Its Own Microbiome**
1-3 **Microbiology Then: The Pioneers**
1-4 **The Microbial World Is Cataloged into Unique Groups**
1-5 **Microbiology Now: Challenges Remain**

Earth's Microbiomes

Space and the universe often appear to be an unlimited frontier. The chapter opener image on the left shows one of an estimated 350 billion large galaxies and more than 10^{24} stars in the known universe. However, there is another invisible frontier here on Earth. This is the microbial universe, which consists of more than 10^{30} **microorganisms** (or **microbes** for short). As the chapter opener image on the right shows, microbes might be microscopic in size, but, as we will see, they are magnificent in their evolutionary diversity and astounding in their sheer numbers.

This global community of microbes and their genes forms Earth's **microbiome**. Today, microbiologists and scientists from many scientific fields are cataloging the microbial diversity of the **biosphere**, the regions of the Earth where living organisms are found. This effort is called the **Earth Microbiome Project**, and its challenge is to characterize Earth's microbial diversity in all its environments, including the oceans, landmasses, and atmosphere. Being that they are so prolific globally, these microbes must play important roles in the very survival of other organisms on the planet.

A major focus of this chapter is to give you a "first look" at microbes. We will examine Earth's microbiomes and then examine the community of microbes that inhabit the human body. We will, learn of the historical events (the "then") that first put microbes on the map, and finally recognize some challenges facing microbiology now.

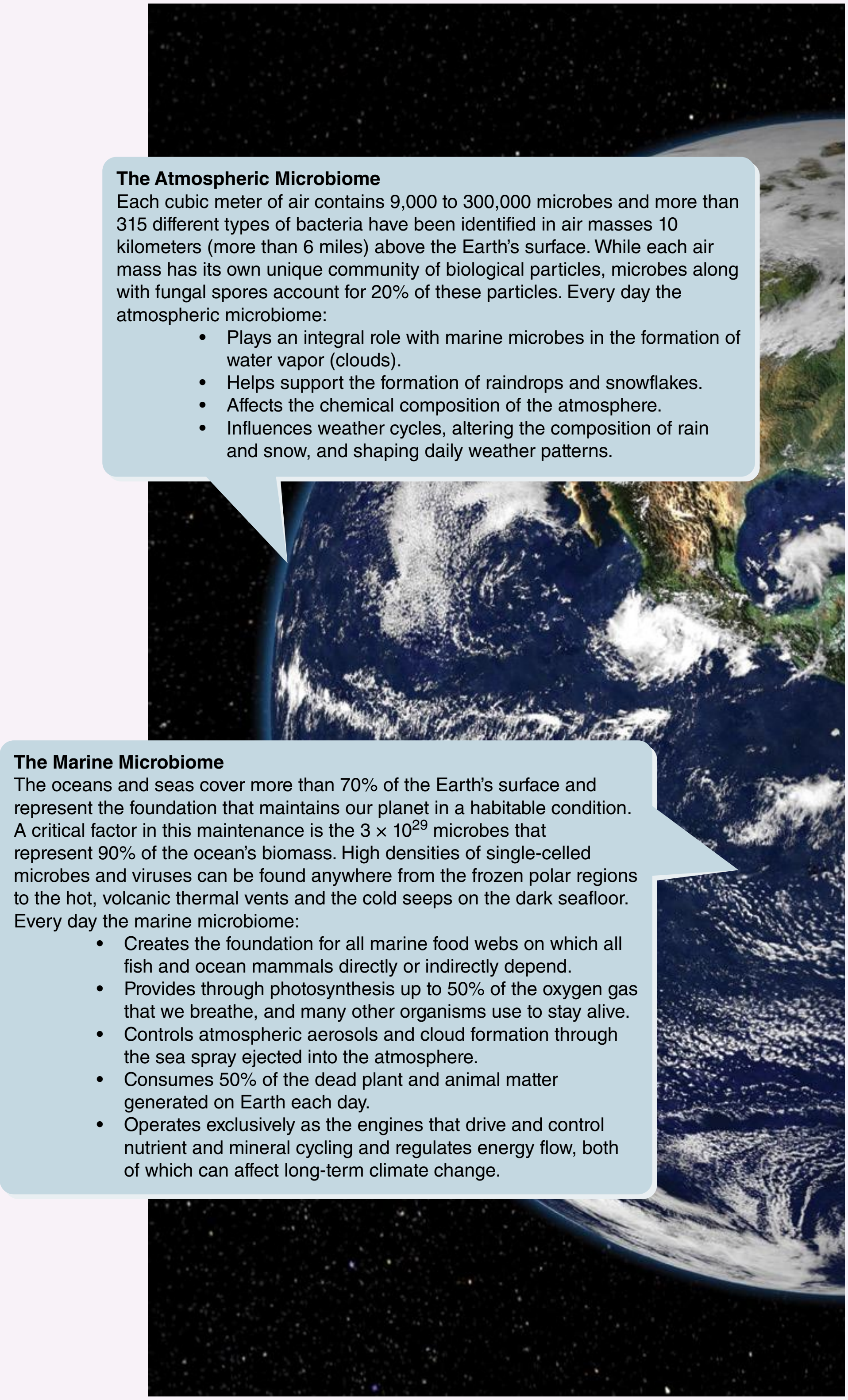
So, first, let's discover what a day is like for some of Earth's microbes in shaping the fundamental life processes around the globe.

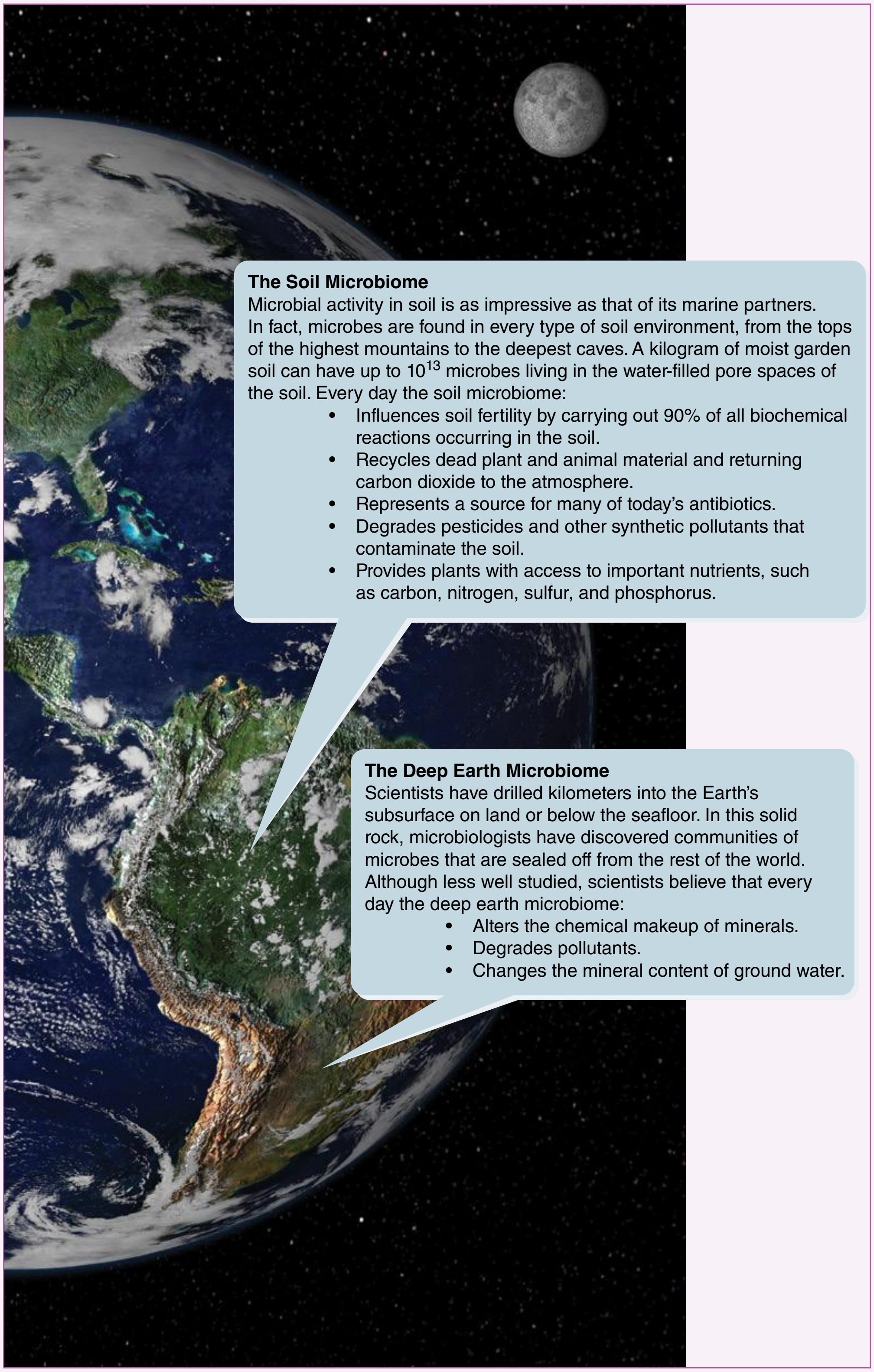
Photographic image of nearby galaxies and stars in space (left) and a light microscope image (right) of bacterial cells (larger dots), viruses (smaller dots), and a diatom (center).

Figure 1-1 SEEING THE CONCEPT

Earth's microbiomes

The microorganisms that comprise Earth's microbiomes represent an untapped source of genetic diversity and chemical transformations of matter and material.




The Soil Microbiome
Microbial activity in soil is as impressive as that of its marine partners. In fact, microbes are found in every type of soil environment, from the tops of the highest mountains to the deepest caves. A kilogram of moist garden soil can have up to 10^{13} microbes living in the water-filled pore spaces of the soil. Every day the soil microbiome:
- Influences soil fertility by carrying out 90% of all biochemical reactions occurring in the soil.
- Recycles dead plant and animal material and returning carbon dioxide to the atmosphere.
- Represents a source for many of today's antibiotics.
- Degrades pesticides and other synthetic pollutants that contaminate the soil.
- Provides plants with access to important nutrients, such as carbon, nitrogen, sulfur, and phosphorus.
The Deep Earth Microbiome
Scientists have drilled kilometers into the Earth's subsurface on land or below the seafloor. In this solid rock, microbiologists have discovered communities of microbes that are sealed off from the rest of the world. Although less well studied, scientists believe that every day the deep earth microbiome:
- Alters the chemical makeup of minerals.
- Degrades pollutants.
- Changes the mineral content of ground water.

KEY CONCEPT 1-1 Microbial Communities Support and Affect All Life on Earth

Almost 4 billion years ago, Earth was a microbial planet. The diverse and numerous microorganisms populating the planet were beginning the processes that would create the environment that sustains and shapes our planet and that has made Earth habitable for larger organisms like plants and animals. Scientists today continue to uncover more key roles being carried out within Earth's microbiome. So, with the aid of SEEING THE CONCEPT (**Figure 1-1** previous page), let's travel around the world and discover some of Earth's microbiomes that constitute the life support system of the biosphere.

The Marine Microbiome Is One of the Largest Microbiomes on the Planet

The oceans and seas cover more than 70% of planet Earth and represent the foundation that maintains our planet in a habitable condition. This foundation is controlled by the marine microbiome, which represents the microorganisms found everywhere from the frozen polar regions to the hot, volcanic thermal vents and the cold seeps on the dark seafloor. This amounts to some 3×10^{29} microbes and represents 90% of the marine **biomass** (total mass of all organisms in an area). Look back at Seeing the Concept (Figure 1-1), which lists several of the daily roles of the marine microbiome in regulating life on Earth.

Viruses are the most abundant infectious agents on Earth. In the oceans, they outnumber the bacteria 10 to 1 (**Figure 1-2**). Although most of these viruses remain uncharacterized, they can infect marine microbes and affect marine life in many ways. For example, marine viruses kill 20% to 40% of all marine bacteria every day and are responsible for swapping 10^{29} genes between bacteria each day. These effects alone suggest that viruses control the course of bacterial evolution and the daily activities in these marine microbiomes. As such, many scientists believe viruses represent the most dominant agents affecting life on Earth.

The Soil Microbiome Shapes the World Around Us

The soil microbiome represents a dynamic group of distinct microbial communities associated with plants, soil animals, and the soil itself. Soil microbial diversity is on a par with that in the marine environments and is no less impressive in its daily activities than that of its marine counterparts. In fact, every time you walk on the soil, you step on billions of microbes (**Figure 1-3**). Moreover, like their cousins in the oceans, they are found in every imaginable environment, from the tops of the highest mountains to the deepest caves. The World Bank reports that almost 40% of the terrestrial

Figure 1-2 The marine microbiome
In this light microscopy image, each large dot is one bacterial cell, and each small dot is a virus normally found in one drop of seawater. (Bar = 10 μm)
Courtesy of Rachel Parsons, Bermuda Institute of Ocean Science.

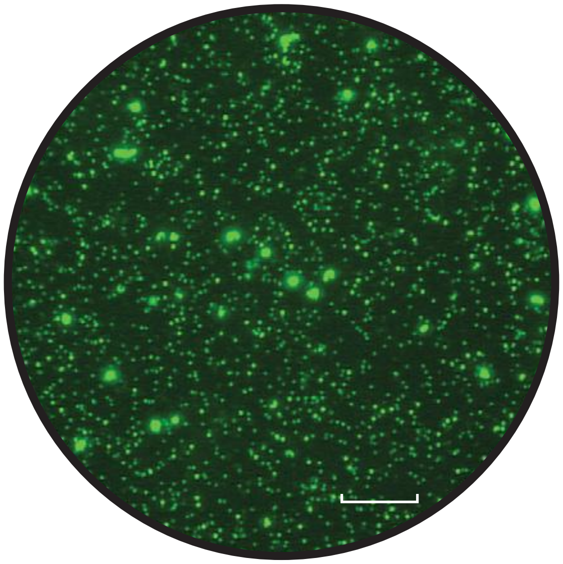
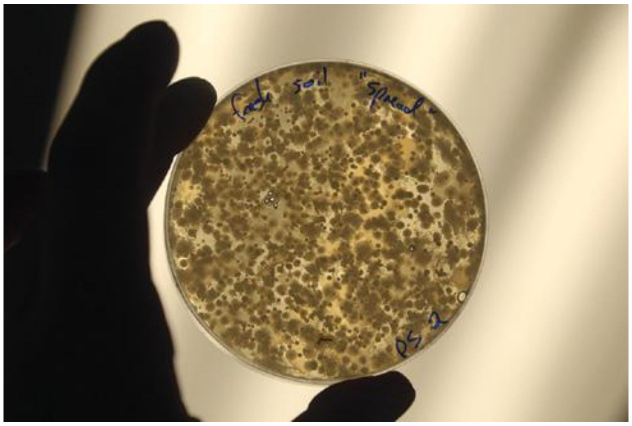


Figure 1-3 The soil microbiome
If a few grains of soil are placed in a culture dish, aggregations of bacteria and fungi (brownish clusters) grow.
© Alexander Gold/Shutterstock.



environment is used for agriculture. Coupled with the fact that a kilogram of moist farming soil can have up to 10^{13} microbes living in the soil's water-filled pore spaces, it becomes clear that the daily activities of these microbes are essential to life. Seeing the Concept (Figure 1-1) lists some of the daily activities carried out by soil microbes. As the drivers of soil chemistry, soil microbes are protectors of the soil's health, and in so doing are helping to feed the world.

The Atmospheric Microbiome Carries a Diverse Community of Bacteria and Fungi

When seen from space, planet Earth has been referred to as a "pale blue dot" washed in white clouds. In this atmosphere though, events like soil erosion hurl soil microbes, ocean evaporation lifts marine microbes, and coughing and sneezing launch microbes and viruses into the air. In fact, more than 315 different types of bacteria have been identified in air masses 10 kilometers (more than 6 miles) above the Earth's surface. These microbes, along with fungal spores, account for 20% of all particles—biological and nonbiological—in the atmosphere (**Figure 1-4**). Although less studied than the ocean and soil microbiomes, scientists believe that these atmospheric communities also perform essential daily roles (see Seeing the Concept in Figure 1-1).

Today, microbiologists believe they have discovered only about 2% of all microbes. Besides the oceans, soil, and atmosphere, where else are microbes found?

Figure 1-4 The atmospheric microbiome
If an air sample from as high up as 10 kilometers (6.2 miles) is exposed to nutrients in a culture dish, many different species of bacteria (small dots) and fungi (larger fuzzy circles) soon appear.

The Deep Earth Microbiome Is Home to Vast and Unusual Communities of Microbial Life

Today, scientists are beginning a real-life journey toward the center of the Earth. These scientists have drilled up to 5 kilometers (3 miles) into the Earth's living underworld (subsurface) on land or below the seafloor (**Figure 1-5**). In the water-filled pore spaces of solid rock, they have discovered another frontier composed of microbes (primarily bacteria and fungi) that are sealed off from the rest of the world and live in perpetual darkness. These so-called "deep microbes" that survive in these inhospitable conditions (e.g., extreme heat, no light, sparse nutrients) might make up 70% of the microbes on Earth and more than 50% of the biomass of the planet. These relatively slow-growing microbes often are called "zombie" bacteria because they seem to be barely alive. Some might be up to 100 million years old, reproducing only once a century. Yet, as listed in Figure 1-1, they might have roles in the daily functions of the planet equal to those of the other microbiomes of the biosphere.

Today, the workforce comprising the global microbiome is still being cataloged, and their numbers and daily activities keep growing. As Louis Pasteur, one of the fathers of microbiology, once stated, "Life [plant and animal] would not long remain possible in the absence of microbes."

Figure 1-5 The deep Earth microbiome
Dr. Beth Orcutt (left front row) from the Bigelow Laboratory for Ocean Sciences in Maine and other researchers are trying to understand how life below the seafloor can survive and thrive.

Concept Check 1-1

1. What are microbiomes, and what are some of the roles they play globally?

KEY CONCEPT 1-2 The Human Body Has Its Own Microbiome

The presence and need for microbes can be found much closer to home. Microbiomes cohabit the bodies of all plants and animals. In the case of animals, every animal from termites to bees, cows, and humans has an intimate set of microbial communities associated and coevolving with it. The **human microbiome** (formerly and sometimes still called the "microflora") consists of some 38 trillion microbes composing more than 4,000 different types of bacteria and fungi found on and in the human body. This is greater than the number of cells (30 trillion) forming the human body (**Figure 1-6A**). All human microbiomes do not share the same set of microbes. Rather, each individual has a unique microbiome specific to the skin, the mouth, and the gut that results from physiological differences, age, diet, and geographic location (**Figure 1-6B**). In fact, the belly button alone has a unique combination of more than 50 types of bacteria! Where did these microbial companions come from, and what good are they?

The communities of microbes living on and in the body did not appear by accident. A healthy human fetus is free of most microbes until birth. Then, during and immediately after birth, body surfaces (e.g., skin, mouth, eyes, nose, gut) on and in the newborn that have contact with the environment become populated with a large variety of these microbes. Initially, most come from mother's birth canal during delivery. Soon, this human microbiome is strengthened through contact with microbes coming from caregivers, family members, family pets, foods, and other environmental sources. The result is the development of unique microbial communities of microbes on the skin, in the mouth and respiratory tract, and especially in the gut.

Although some microbes in the body are temporary, most members of the human microbiome spend each day carrying out an amazing array of metabolic reactions. The microbes of the gastrointestinal tract help prevent infectious disease, aid in the breakdown food, provide essential nutrients and vitamins that the body cannot make, and chemically communicate with the brain and immune system. These microbes might even influence the risk of developing obesity, asthma, and allergies. To be human and healthy, we must share our daily lives with homegrown communities of microbes.

Concept Check 1-2

2. Where on and in the body of a healthy human are microbes normally found?
3. Identify some of the roles the human microbiome plays in daily life.

KEY CONCEPT 1-3 Microbiology Then: The Pioneers

One aspect of a microbe's daily life that we have overlooked until now is its role in infectious disease. Only an exceedingly small minority of microbes are responsible for infections and disease. Although such disease-causing agents, called **pathogens**, are rare, some, such as those causing diseases like plague, malaria, and smallpox, throughout history have swept through cities and villages, devastated populations, and killed great leaders and commoners alike. **Coronavirus disease 2019** (COVID-19) is the most recent to join this pandemic group. As a result, microbes have been instrumental in transforming politics, economies, and public health on a global scale. However, only a small minority of microbes are dedicated pathogens.

In this section, we will see how microbes were first discovered and how curiosity and scientific inquiry stimulated the quest to understand the correlation between microbes and infectious disease. To begin our story, we reach back to the 1600s, where we encounter some very inquisitive individuals.

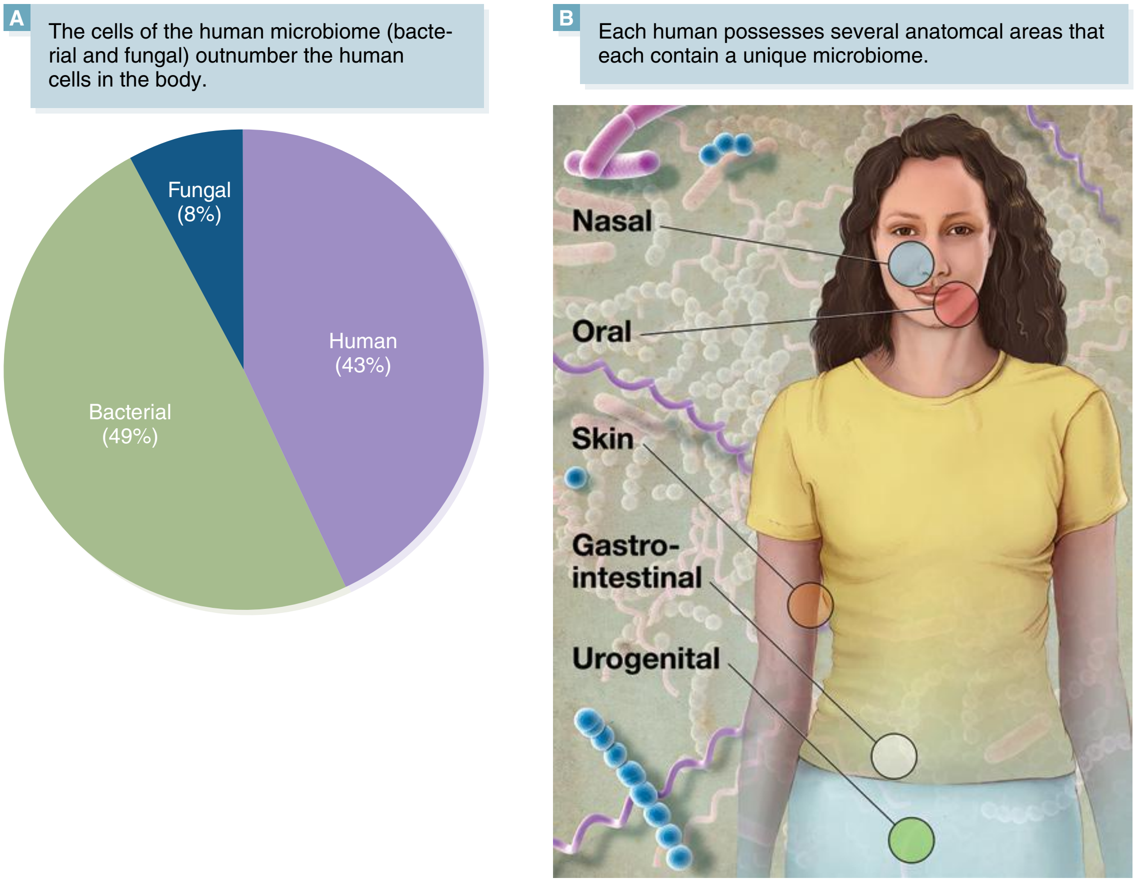
Hooke and Leeuwenhoek Discover the Microbial World

Robert Hooke, an English natural philosopher (the term "scientist" was not coined until 1833), was one of the most inventive and ingenious minds in the history of science. As the Curator of Experiments for the Royal Society of London, Hooke published a book in 1665 called *Micrographia*, in which he took advantage of the magnification abilities of the early microscopes. In this book, he made detailed drawings of many diverse living

Figure 1-6 The human microbiome

The human microbiome comprises all the individual microbial communities that live on or within human tissues (**A**) and corresponding anatomical sites (**B**). ***What is common to all the human body sites having a microbiome?***

B: Courtesy of NIH Medical Arts and Printing.



objects, including fleas, lice, and peacock feathers. Perhaps his most famous description was for the structure of cork, the buoyant, light brown substance obtained from the outer layer of the bark of the cork oak. Seeing "a great many little boxes," he called these boxes *cella* (= "rooms"), and from that observation, today we have the word "cell" to describe the basic unit of life (**Figure 1-7**).

Micrographia represents one of the most important books in science history. It awakened the learned and general population of Europe to the world of the very small, revolutionized the art of scientific investigation, and showed that the microscope was an important tool for unlocking the secrets of an unseen world: the world of the cell.

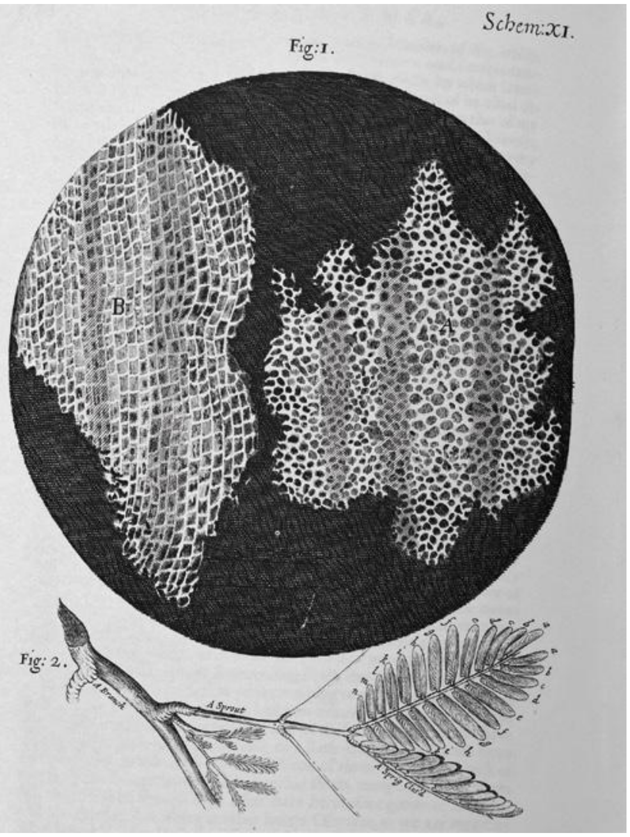
At this same time, across the North Sea in Delft, Holland, Antoni van Leeuwenhoek was grinding single pieces of glass into fine magnifying lenses. As a successful tradesman and dry goods dealer, he used these hand lenses to inspect the quality of his cloth. Placing such a lens between two metal plates riveted together, Leeuwenhoek's "simple microscope" could greatly out magnify Hooke's microscope (**Figure 1-8A, B**).

Aware of Hooke's *Micrographia*, Leeuwenhoek turned his microscope to the invisible world. Beginning in 1673 and until his death in 1723, Leeuwenhoek communicated his microscope observations through some 300 letters sent to England's Royal Society of London, one of the most respected scientific societies of the time. In 1674, one of his first letters described a sample of lake water. Placing the sample before his lens, he described hundreds of moving particles. He thought they must be tiny living animals, so he called them **animalcules** (*cul* = "little"). This discovery represents one of the most important observations in history because Leeuwenhoek had described and illustrated for the first time the microbial world.

Equally significant was a 1676 letter in which he describes and draws the first unmistakable observations of bacteria (**Figure 1-8C**). Among the other letters sent to the Royal Society, he described all the different types of microbes (except viruses) that we know of today. This included details of yeast cells, threadlike fungi, and microscopic algae and protozoa.

Figure 1-7 Hooke's *Micrographia*
Micrographia was the first important work involving microscopy. Hooke's drawing and description of cork was the first use of the word "cell" to describe biological objects.

Robert Hooke. Micrographia: or, Some physiological descriptions of minute bodies made by magnifying glasses. London: J. Martyn and J. Allestry, 1665. (first edition).



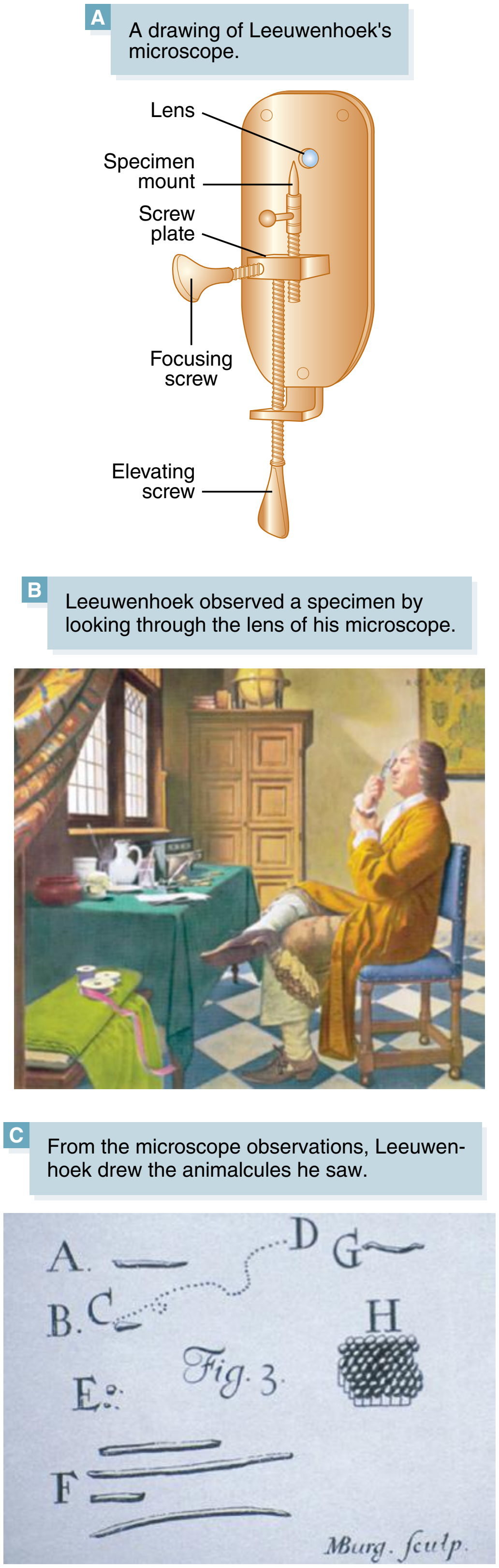
The process of observation is an important skill for all scientists and remains the cornerstone of all scientific inquiry. Hooke and Leeuwenhoek are excellent examples of individuals with sound observational skills. Unfortunately, Leeuwenhoek invited no one to work with him, nor did he show anyone how he made his lenses. Thus, naturalists at the time found it difficult to repeat and verify his observations, which also are key components of scientific inquiry. Still, Leeuwenhoek's observations of animalcules opened yet a second door to another entirely new microscopic world: the world of the microbe.

Concept Check 1-3A

4. How were the first microbes discovered?
5. If you were alive in Leeuwenhoek's time, how would you explain the origin for the animalcules he saw with his simple microscope?

Figure 1-8 Viewing animalcules
To view his animalcules, Leeuwenhoek used a simple microscope with one lens (**A**). When held up to the light (**B**), Leeuwenhoek could see his animalcules (**C**). ***Why would Leeuwenhoek believe his living (and moving) creatures were tiny animals?***

B: Collection of the University of Michigan Health System, Gift of Pfizer, Inc. (UMHS.15); **C:** © Royal Society, London.



For many years, natural philosophers debated the origins of Leeuwenhoek's animalcules. Some said they arose from a "vital force" that reorganized dead and decaying matter into organized life. Others countered that the animalcules only arose from other living animalcules, often found in the air. Then, in 1861, the French chemist and scientist Louis Pasteur (**Figure 1-9A**) settled the debate. Through an elegant series of experiments, he showed that animalcules (microbes) do come from others present in the air. **Investigating the Microbial World 1** outlines the process of scientific inquiry and Pasteur's experiments.

So, Pasteur was able to prove that microbes only come from the reproduction of other microbes. However, no one before Pasteur had considered whether these microbes found in the air could be agents of infectious disease. Then, in the early 1850s, research into the association between microbes and the disease process blossomed. Over the next 60 years, the foundations would be laid for the maturing process that has led to the modern science of microbiology. This period is referred to as the classical or first Golden Age of microbiology.

Pasteur Proposes That Germs Cause Infectious Disease

Trained as a chemist, Louis Pasteur believed that problems in science could be solved in the laboratory with the results having practical applications.

Fermentation

Always one to tackle big problems, Pasteur set out to understand the chemical process of fermentation. The prevailing theory in the early 1850s held that fermentation was strictly a chemical process, and that the yeasts needed for fermentation were simply inert chemical "globules" that stimulated the process. Pasteur was unconvinced. His microscope observations consistently revealed large numbers of tiny yeast cells in fermented juice. When he mixed yeast in a sugar–water solution in the absence of air, the yeast multiplied and converted the sugar to alcohol. Fermentation, then, was a biological process, and yeasts were living agents responsible for the fermentation process.

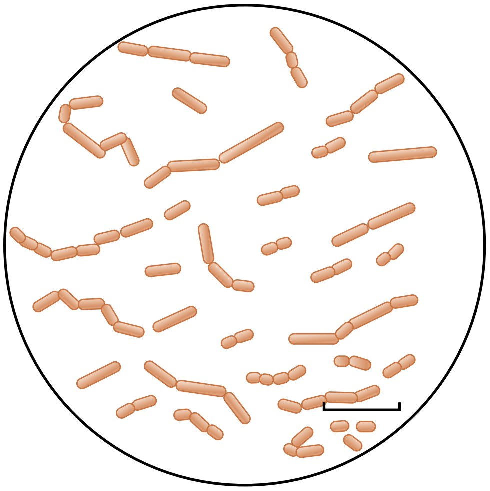
On the applied side, Pasteur demonstrated that wines, beers, and vinegar each contained different and specific types of microorganisms that had specific properties. For example, in studying a local problem of wine souring, he observed that only the soured wines contained populations of bacterial cells (**Figure 1-9B**). Pasteur concluded that these cells must

Figure 1-9 Louis Pasteur and fermentation bacteria
Louis Pasteur (**A**) believed bacteria spoiled wine, as he could see these cells through his microscope (**B**).

A: Courtesy of National Library of Medicine.

A Louis Pasteur as a 46-year-old professor of chemistry at the University of Paris.

B Pasteur believed that bacterial cells, similar to these that he saw by with the microscope, could cause the souring of wine. (Bar = 5 µm)



have contaminated a batch of yeast and, as another example of a biological process, produced the acids that caused the souring. Pasteur recommended a practical solution for the "wine disease" problem: heat the wine gently to kill the harmful bacterial cells but not so strongly as to affect the quality of the wine. His controlled heating technique solved the wine problem and, what would become known as **pasteurization**, soon was applied to other products. Today, pasteurization is a universal method used to kill pathogens and retard spoilage in milk and many other foods and beverages.

If "wine disease" could be caused by tiny, living bacteria, Pasteur reasoned that infections and disease

Investigating the Microbial World 1

Experimentation and Scientific Inquiry

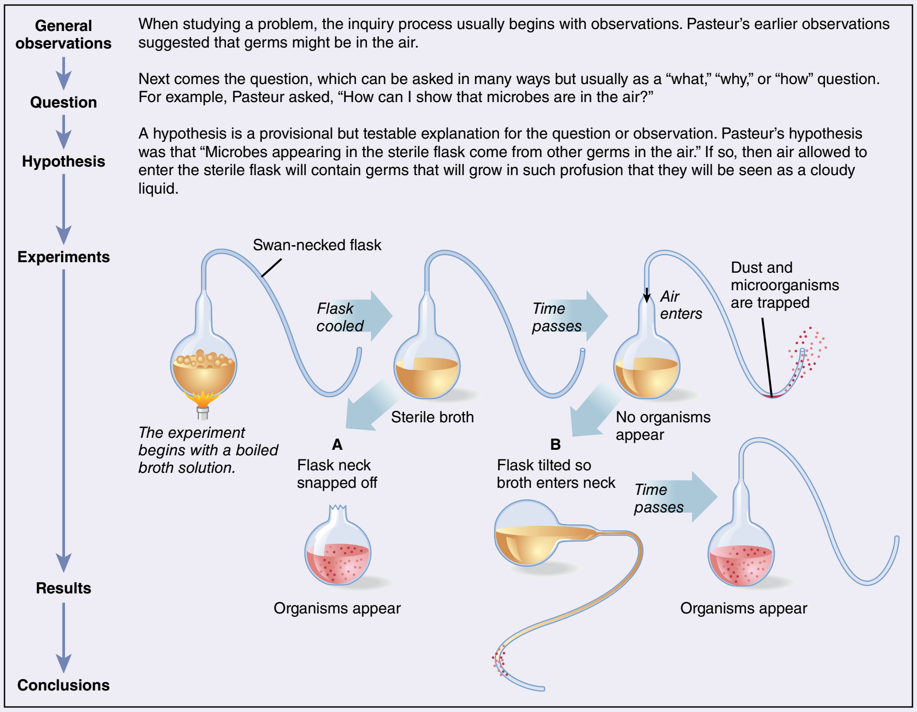
Science certainly is a body of knowledge, but science also is a process—a way of learning. Often, we accept and integrate into our understanding new information because it appears consistent with what we believe is true. But, are we confident our beliefs are always in line with what is accurate? To test or challenge current beliefs, scientists must present logical arguments supported by well-designed and carefully performed **experiments**.

The Components of Scientific Inquiry

There are many ways of finding out the answer to a problem. In science, **scientific inquiry**—or what commonly has been called the "scientific method"—is a variety of procedures used to investigate a problem. Let's understand how scientific inquiry works by following the logic of the experiments Louis Pasteur published to show that microbes are present in the air. Pasteur set up the following **experiment** to test the **hypothesis**.

Pasteur and the microbes in air

First, broth in a swan-necked flask (flask with a long, tapered neck) is boiled. If allowed to cool and remain undisturbed, air can enter the flask, but the curvature of the neck traps dust particles and microorganisms, preventing them from reaching the broth. If a similar flask of sterilized broth has the neck snapped off **(A)**, or the flask is tipped so broth enters the neck **(B)**, organisms will contact the broth and grow.



Results

- No growth (microbes) was seen in the intact flasks.
- Microbes (cloudy liquid) were found in the flasks after the neck was snapped off or the flask tipped so the broth entered the neck.

Conclusions

Let's analyze the results. Pasteur had a preconceived notion of what should happen if his hypothesis was correct. In his experiments, only one "variable" (an adjustable condition) changed. In the experiment, the flasks were left intact or they were exposed to the air by breaking the neck or tipping the flask. Pasteur kept all other factors the same; that is, the broth was the same in each flask, it was heated the same length of time, and similar flasks were used in each experiment.

Thus, the experiment had rigorous "controls" (the comparative condition), which were the intact swan-necked flasks.

Pasteur's finding that no microbes appeared in these flasks is interesting but tells us little by itself. Its significance comes by comparing this to the broken-neck (or tipped) flasks where microbes quickly appeared. These experiments validated his hypothesis.

Hypothesis and Theory

A "**theory**" is defined as a hypothesis that has been tested and shown to be correct every time by many separate investigators. So, at some point, if validated by others, enough evidence exists to say a hypothesis is now a theory. However, theories are not written in stone. They are open to further experimentation, and so can be proven false.

As a side note, today a theory often is used incorrectly in everyday conversation and in the news media. In these cases, a theory is equated incorrectly with a hunch or belief—whether there is evidence to support it or not.

also might be caused by other microorganisms in the environment—what he called **germs**.

Silkworm Disease

Pasteur sought more evidence for his germ theory idea. In 1865, he had the opportunity to study pébrine, an infectious disease of silkworms. After several setbacks and 5 years of work, he finally identified a new type of germ, unlike the bacterial cells and yeast he had observed with his microscope. These tiny germs, which he called "corpuscular parasites," were the infectious agent in silkworms and on the mulberry leaves fed to the worms. By separating the healthy silkworms from the diseased silkworms and their contaminated food, he managed to quell the spread of the silkworm disease. Today, we know the "corpuscular parasites" were a type of protozoan.

From these scientific investigations, Pasteur formulated the **germ theory of disease**, which held that some microorganisms are responsible for infectious disease. However, to validate the germ theory, what Pasteur was missing was the ability to isolate a specific germ from a diseased animal and demonstrate that the isolated germ caused that same disease in another healthy animal.

Concept Check 1-3B

6. How did Pasteur's studies of wine fermentation and souring suggest to him that germs might cause human infectious disease?

7. How did Pasteur's studies of pébrine influence his idea for the germ theory of disease?

Koch Formalizes Standards to Equate Germs with Infectious Disease

Pasteur's idea that germs caused disease stimulated others to investigate the association of microbes with infectious disease. Among these so-called "microbe hunters" was Robert Koch, a German country doctor. In the 1870s, Koch's primary interest was anthrax, a deadly blood disease in cattle and sheep. He wanted to know if there was a specific germ that caused anthrax.

Koch tried to define a set of rules to establish a link between a specific microbe and anthrax. In 1875, Koch injected mice with the blood from sheep suffering from anthrax. He noticed the mice soon developed the same disease symptoms seen in the sheep. Next, he isolated a few rod-shaped bacterial cells from the blood and, with his microscope, watched for hours as the bacterial cells multiplied, formed tangled threads, and finally reverted to spores. He then took several spores on a sliver of wood and injected them into healthy mice. The signs of anthrax soon appeared, and when Koch autopsied the animals, he found their blood swarming with the same type of bacterial cells. Here was the first evidence that a specific germ was the infectious agent of a specific disease.

When Koch presented his final version of the guidelines at a scientific meeting, fellow scientists were astonished. Here was the verification of the germ theory that had eluded Pasteur. Koch's guidelines became known as **Koch's postulates** and were quickly adopted as the formalized standards for implicating a specific germ with a specific disease. **SEEING THE CONCEPT** (**Figure 1-10**) outlines the four-step process.

In doing his studies, Koch found that growing pure cultures of bacterial cells was cumbersome. Then, in 1880, he observed a slice of potato on which small masses of bacterial cells, which he termed **colonies**, were multiplying in number. Koch tried adding gelatin to his broth to prepare a similar solid culture surface. He then inoculated bacterial cells on the surface and set the dish aside to incubate. Within 24 hours, visible colonies were growing on the surface, each colony representing a **pure culture** containing only one bacterial type. By 1882, a polysaccharide called **agar** that was derived from marine algae replaced gelatin as Koch's preferred solidifying agent, as **MicroFocus 1-1** recounts. Today, the agar plate containing nutrients remains the standard way to culture microorganisms.

Germ identification using Koch's postulates soon became the normal method of work. Koch's lab focused on disease causation (**etiology**). He identified the bacterial agents responsible for tuberculosis (1882) and cholera (1883). Pasteur's lab, on the other hand, was more concerned with preventing disease through vaccination. This culminated in 1885, when Pasteur's rabies vaccine saved the life of a young boy who had been bitten by a rabid dog.

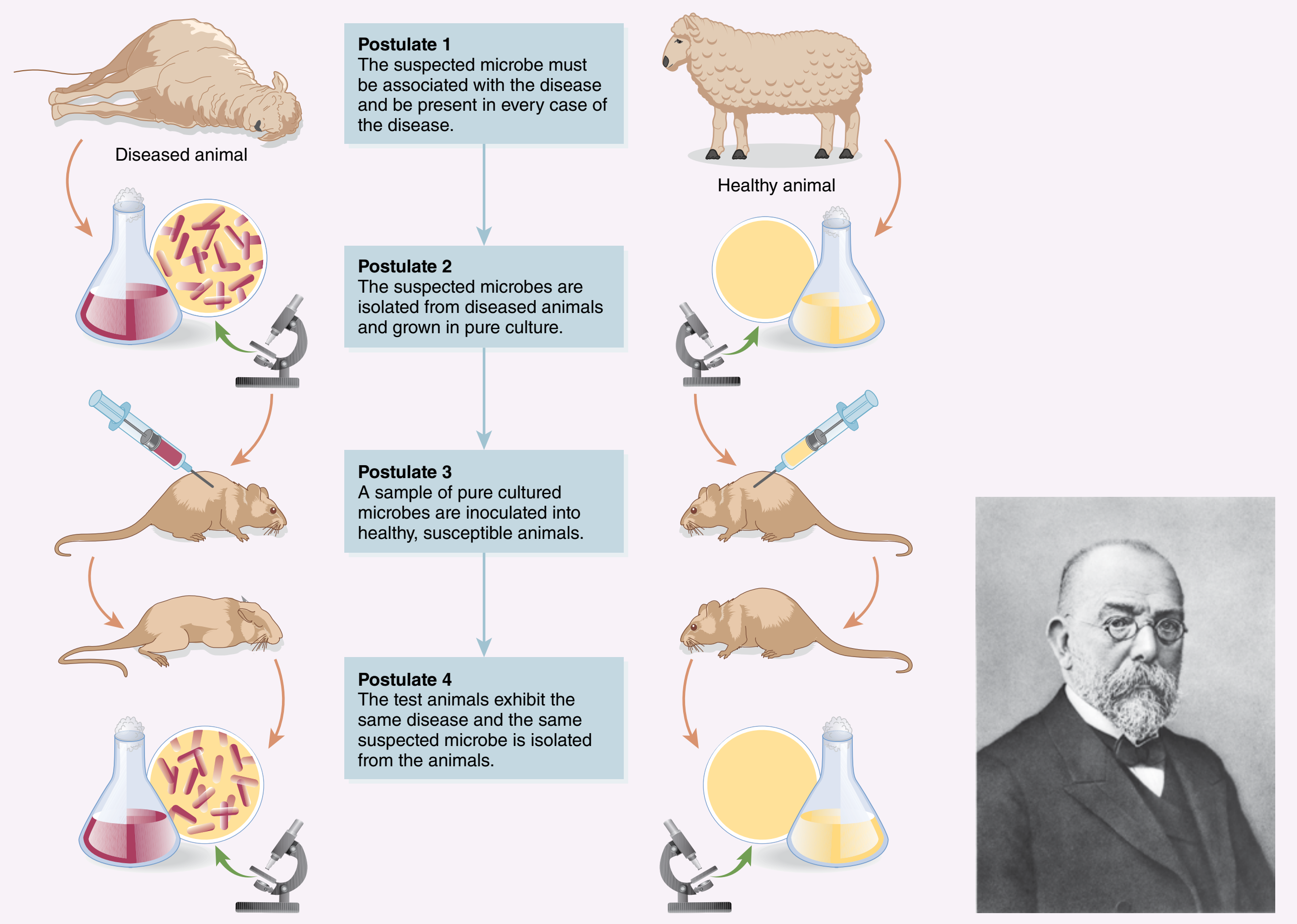
By the turn of the century, the germ theory of disease had set a new course for studying and treating infectious disease. The detailed studies carried out by Pasteur and Koch made the discipline of **bacteriology**, the study of bacterial organisms, a well-respected field of study (**Figure 1-11**).

Figure 1-10 SEEING THE CONCEPT

Koch's postulates

Robert Koch (inset) developed a set of guidelines to relate a specific microorganism to a specific disease. ***What is the relationship between postulates 2 and 4?***

Inset: Courtesy of National Library of Medicine.



Pasteur and Koch inspired more scientists to be microbe hunters. Many of these individuals discovered other germs (bacterial, fungal, protozoal, viral) causing other human diseases (**Table 1-1**). Such discoveries established other disciplines within the field of microbiology (see Figure 1-11).

Concept Check 1-3C

8. Explain why Koch's postulates were critical to validating the germ theory of disease.
9. How did the development of pure cultures advance the germ theory of disease?

KEY CONCEPT 1-4 The Microbial World Is Cataloged into Unique Groups

As time went on, more and more microorganisms and viruses were identified and studied. Before we briefly survey what is known today about the basic characteristics of these microbial groups, we need to understand what an organism is. Simply defined, an **organism** is any living system consisting of one or more cells. Thus, a "microorganism" is a living system consisting of an extremely small (microscopic) cell.

MicroFocus 1-1

Jams, Jellies, and Microorganisms

One of the major developments in microbiology was Robert Koch's use of a solid culture surface on which bacterial colonies would grow. He accomplished this by solidifying beef broth with gelatin. When inoculated onto the surface of the nutritious medium, bacterial cells grew vigorously at room temperature and produced discrete, visible colonies.

On occasion, however, Koch was dismayed to find that the gelatin turned to liquid because some bacterial species produced a chemical substance that digested the gelatin. Moreover, gelatin liquefied at the warm incubator temperatures commonly used to cultivate many bacterial species.

An associate of Koch's, Walther Hesse, mentioned the problem to his wife and laboratory technician, Fanny Hesse. She had a possible solution. For years, she had been using a seaweed-derived powder called agar (pronounced ah'gar) to solidify her jams and jellies. Agar was valuable because it mixed easily with most liquids, and once gelled, it did not liquefy at warm incubator temperatures.

In 1881, Walther Hesse recommend agar to Koch. Soon Koch was using it routinely to grow bacterial species, and, in 1884, he first mentioned agar in his paper on the isolation of the bacterial organism responsible for tuberculosis. It is noteworthy that Fanny Hesse is one of the first Americans (she was originally from New York City) to make a significant contribution to microbiology.

Another key development, the common petri dish (culture plate), also was invented about this time (1887) by a German microbiologist Julius Petri, who also was one of Koch's assistants.

Fanny Hesse

Courtesy of National Library of Medicine.

Figure 1-11 Microbiology disciplines
This simple concept map shows the relationship between microbiology and its various disciplines.

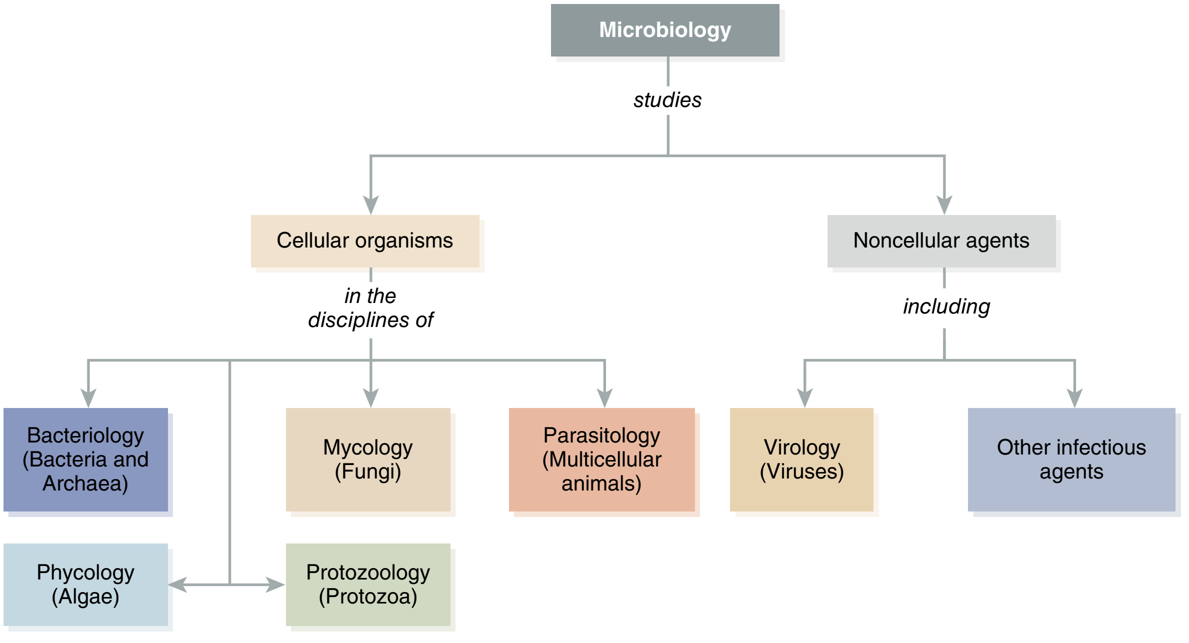


Table 1-1 Other International Scientists Who Identified Specific Human Pathogens During the Golden Age of Microbiology

Investigator (Year)	Country	Disease (Infectious Agent)
Otto Obermeier (1868)	Germany	Relapsing fever (bacterium)
Gerhard Hansen (1873)	Norway	Leprosy (bacterium)
Albert Neisser (1879)	Germany	Gonorrhea (bacterium)
Charles Laveran (1880)	France	Malaria (protozoan)
Karl Eberth (1880)	Germany	Typhoid fever (bacterium)
Edwin Klebs (1883)	Germany	Diphtheria (bacterium)
Arthur Nicolaier (1884)	Germany	Tetanus (bacterium)
Theodore Escherich (1885)	Germany	Infant diarrhea (bacterium)
Albert Fraenkel (1886)	Germany	Pneumonia (bacterium)
David Bruce (1887)	Australia	Undulant fever (bacterium)
Anton Weichselbaum (1887)	Austria	Cerebrospinal meningitis (bacterium)
A. A. Gärtner (1888)	Germany	Food poisoning/salmonellosis (bacterium)
William Welch and George Nuttall (1892)	United States	Gas gangrene (bacterium)
S. Kitasato and A. Yersin (1894)	Japan and France	(Independently) Bubonic plague (bacterium)
Emile van Ermengem (1896)	Belgium	Botulism (bacterium)
Kiyoshi Shiga (1898)	Japan	Bacterial dysentery (bacterium)
Walter Reed (1900)	United States	Yellow fever (virus)
Robert Forde and Joseph Everett Dutton (1902)	Great Britain	African sleeping sickness (protozoan)
Fritz Schaudinn and Erich Hoffman (1903)	Germany	Syphilis (bacterium)
Jules Bordet and Octave Gengou (1906)	France	Whooping cough/pertussis (bacterium)
George McCoy and Charles Chapin (1911)	United States	Tularemia (bacterium)

Despite their microscopic size, microorganisms share a common set of characteristics, or emerging properties, with all living organisms. These include:

- **Hereditary Material.** Information in the form of DNA is used by all organisms for cell function and reproduction.
- **Complex Biochemical Patterns (Metabolism).** The information in an organism's DNA controls metabolism, which also requires the uptake of energy to power these reactions.
- **Reproduction.** During cell division, the complete set of genetic information is replicated and passed to descendant cells.
- **Response to Stimuli.** Cells and organisms seldom live in isolation but rather interact in many different ways by responding to stimuli.
- **Evolutionary Adaptation.** Cell and organism changes (adaptations) over time provide those best suited to the environment the best chance of survival.

Beside the remarkable unity of characteristics, the cells of all organisms are of two differing types: prokaryotic and eukaryotic. **Prokaryotic cells** (*pro* = "before"; *karyo* = "nucleus") have their genetic information in the form of DNA, but it is not localized within a structure called the cell nucleus. They also lack most of the specialize internal cell structures typical of other microbes and multicellular organisms. Such single-celled organisms are called **prokaryotes**. **Eukaryotic cells** (*eu* = "true") have a distinct cell nucleus and numerous specialized internal structures called **organelles**. Such organisms are called **eukaryotes**.

The Prokaryotes: Bacteria and Archaea

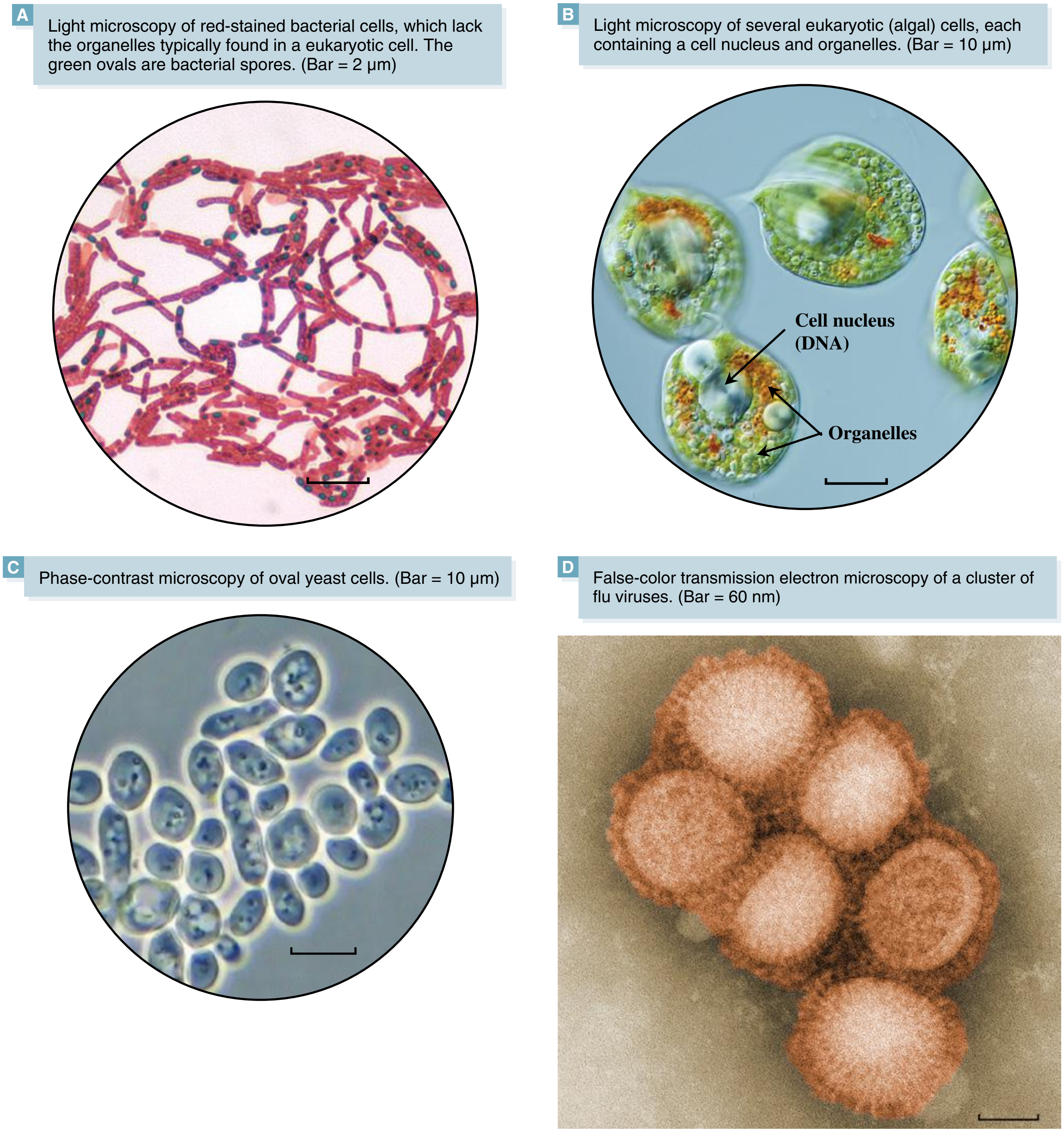
More than 200,000 different types of prokaryotes have been described, and scientists estimate there might be many millions of different types in nature. The prevalence of bacteria has made them the most intensively studied group of microorganisms since the time of Pasteur and Koch.

Most **bacteria** are small, single-celled (unicellular) organisms, although some form filaments, and the majority associate into "multicellular" communities called **biofilms** that often compose a microbiome. These organisms include all bacteria of medical importance. Almost all bacterial cells have a rigid cell wall, and many common ones are spherical, spiral, or rod shaped (**Figure 1-12A**). Many get their food (nutrients) from the environment, although some make their own food through photosynthesis.

In addition to the disease-causing members, some bacteria are responsible for food spoilage, whereas others are useful in the food industry. Many bacterial members, along with several fungi, are **decomposers**,

Figure 1-12 The microbial menagerie
Microscopy images (**A-D**) of prokaryotic and eukaryotic cells, and viruses.

A & D: Courtesy of CDC; B: © Lebendkulturen.de/Shutterstock; C: © Heribert Cypionka.



organisms that bring about the release and reuse of nutrients from dead organisms. They are essential to Earth's microbiomes mentioned at the beginning of this chapter.

Based on recent biochemical, molecular, and gene-sequencing studies, many bacterial organisms have been reassigned into another unique evolutionary group of prokaryotes called the **Archaea**. Although archaeal cells resemble bacterial cells when observed with the microscope, many were originally identified in environments that are extremely hot (such as the Yellowstone hot springs), extremely salty (such as the Dead Sea), or of extremely low pH (such as acid mine drainage). Since then, many other archaeal organisms have been found in temperate soils and water. Others, along with bacteria, are an integral part of the microbiome in the digestive tracts of animals. No archaeal members are known to be pathogens, but like the bacterial microbes, they are an important part of Earth's microbial workforce.

The Microbial Eukaryotes: Protists and Fungi

The **protists** consist mostly of the so-called **protozoa** and the single-celled **algae**. They are about 10 to 50 times larger than prokaryotic cells. Protists are the most diverse of all of the eukaryotic groups, including plants and animals. Scientists have identified more than 200,000 different protists, with many more yet to be discovered.

Some protists are free living, whereas others live in association with plants or animals. Protists obtain nutrients in different ways. The protozoa lack a cell wall and absorb nutrients from the surrounding environment or ingest smaller microorganisms, including bacteria. The unicellular, colonial, and filamentous algae have a rigid cell wall and can carry out photosynthesis (**Figure 1-12B**). Although most protists are harmless, some protozoa are among the most clinically important pathogens of humans, capable of causing malaria, several types of diarrhea, and sleeping sickness.

The **fungi** are all nonphotosynthetic eukaryotes. About 125,000 species of fungi have been described; however, scientists estimate there might more than 6 million different species in nature.

Some fungi grow as unicellular **yeasts**, which are slightly larger than many bacteria (**Figure 1-12C**). Other fungi grow as filamentous networks called **molds**, which usually are found in warm, moist places. Fungi secrete digestive enzymes that break down nutrients into smaller bits that can be absorbed easily across the cell wall. Fungi, therefore, live in their own food supply. If that source of food is a human, diseases such as ringworm or vaginal yeast infections might result.

Fungi have an immense impact on environmental health, biodiversity, ecology, agriculture, and industry. For example, together with many bacterial species, numerous molds play a major role as decomposers. In the pharmaceutical industry, some fungi are sources for useful products, such as antibiotics. Other molds are used in the food industry to impart distinctive flavors in foods such as cheeses.

Other Infectious Agents: The Viruses

Viruses are "infectious agents," some version of which potentially can infect organisms at every scale, from bacteria to tulips to blue whales. Scientists suggest there might be more than 100 million different viruses. To put this in perspective, Carl Zimmer, the popular science writer, said that "If you were to stack one virus on top of another, you'd create a tower that would stretch beyond the moon, beyond the sun, beyond Alpha Centauri, out past the edge of the Milky Way, past neighboring galaxies, to reach a height of 200 million light years."

Because they lack cellular structure, viruses are not organisms. They have genetic material in the form of DNA or RNA (but not both). The material is surrounded by a protein coat. Viruses infect organisms for one reason only: to replicate; that is, to make more of themselves. However, although viruses have the genetic information needed to direct their own replication, they need the metabolic machinery and chemical building blocks found inside living cells to carry out the replication process. By affecting living organisms, viruses have played a crucial role in the evolution and adaptability of life. Most viruses do not cause disease and death, with only a small percentage affecting humans. The viruses that cause Ebola, measles, AIDS, the flu, and COVID-19 are a few notable examples (**Figure 1-12D**).

Table 1-2 summarizes the general characteristics of the different groups of microorganisms and viruses.

Concept Check 1-4

10. Explain the difference between prokaryotes and eukaryotes.
11. Identify the differences between the groups of eukaryotic microbes.
12. Describe why viruses are called infectious agents rather than organisms.

Table 1-2 Distinguishing Characteristics of the Major Groups of Microorganisms and Viruses

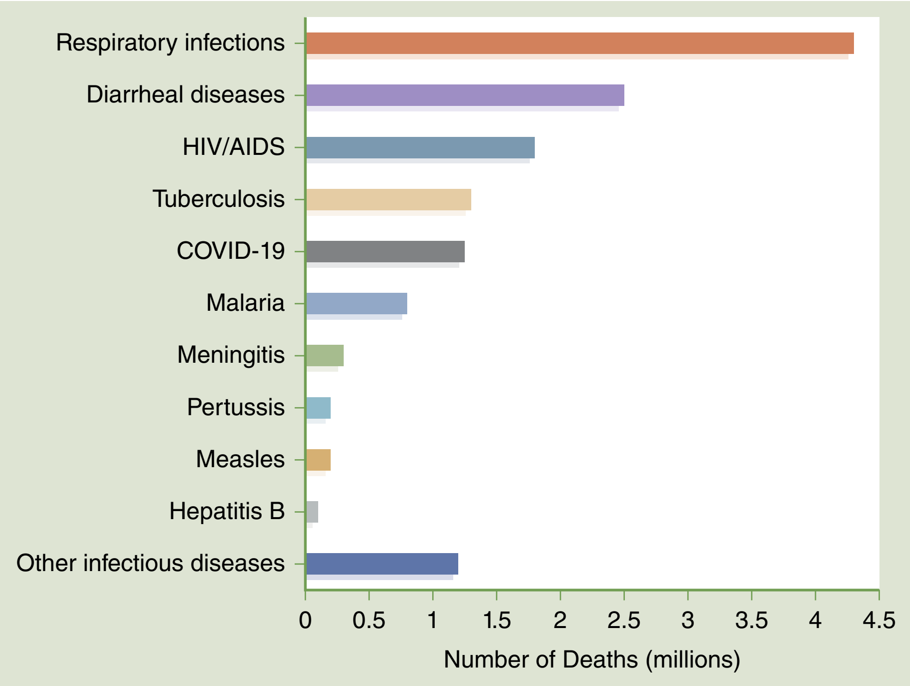
Group	Presence of Cellular Structure	Prokaryote or Eukaryote	Genetic Material	Potential Pathogens
Bacteria	Yes	Prokaryote	DNA, but not in a cell nucleus	Some; most are harmless
Archaea	Yes	Prokaryote	DNA, but not in a cell nucleus	No known pathogens
Fungi	Yes	Eukaryote	DNA in a cell nucleus	Some; most are harmless
Protists	Yes	Eukaryote	DNA in a cell nucleus	Some; most are harmless
Viruses	No	Neither	DNA or RNA	Many

KEY CONCEPT 1-5 Microbiology Now: Challenges Remain

Microbiology is one of the most intensively studied fields in the biological sciences, in part due to the basic science and applied science topics described thus far in this chapter. However, microbiology also faces several challenges, many of which concern infectious diseases that are responsible for millions of illnesses each year and responsible for 16% of all deaths globally (**Figure 1-13**). Until 2020, the World Health Organization (WHO) over the last decade had declared four **global health emergencies**, which represent serious public health events that endanger international public health and global populations. Two of them were the Ebola virus epidemic in West Africa in 2014 to 2016 and the Zika virus disease epidemic that spread through the Americas in 2015 to 2016. Then, in 2020, there was the COVID-19 pandemic. In fact, according to the WHO, over the past 30 year, the number of disease outbreaks globally has increased threefold, from 1,000 per year to more than 3,000 per year.

Figure 1-13 Global mortality from infectious diseases
On a global scale, some 15 million people die each year from infectious diseases. Estimated deaths from COVID-19 for 2020 have been included. ***Can you identify what some of the "other infectious diseases" might be?***

Data from World Health Organization. *World Health Statistics 2011*. Retrieved from: https://www.who.int/whosis/whostat/2011/en/. Accessed February 7, 2019. COVID-19: Johns Hopkins Coronavirus Research Center.



Here are a few of the major challenges facing microbiology today.

Drug-Resistant Pathogens

Today, many people around the world often are given or ask for antibiotics or other antimicrobial drugs to help fight a bacterial infection they have contracted. Unfortunately, the effectiveness of these drugs to treat such infections is weakening. The reason is that many pathogens have become resistant to one or more of these drugs.

The vast majority of antibiotics were discovered in the 1950s and 1960s. It was believed by many in the medical community at the time that bacterial infections in humans finally would be vanquished and no longer pose a threat due to the effectiveness of these drugs. Unfortunately, many health experts did not recognize that bacteria have a natural ability to develop resistance to antibiotics. Pathogens can undergo beneficial mutations or acquire new genes from other bacteria for antibiotic resistance. Warnings from scientists that bacteria were becoming resistant to antibiotics largely went unnoticed. Today, antibiotic resistance has resulted in many previously effective therapies becoming obsolete, leaving fewer treatment options for many infections (**Figure 1-14**). Although antibiotics have saved the lives of millions of individuals, since 1980 deaths from most major infectious diseases in the United States have declined by only 20%.

Perhaps the most pressing issue facing microbiology today is the increased number of bacteria and other microbes that have become resistant to multiple antibiotics. Such **superbugs** are becoming harder and harder to treat effectively largely due to human activities and behavior. The abuse and misuse of antibiotics by the medical profession and the public has created an environment that encourages the development of antibiotic resistance by once-susceptible pathogens. Consequently, a global crusade has been waged to restrain the inappropriate use of these drugs by doctors and to educate patients not to demand antibiotics in situations that do not call for them.

The challenge facing microbiologists and the medical community now is to find new and effective antibiotics to which pathogens will not develop resistance quickly before the current arsenal is useless. Unfortunately, the growing threat of antibiotic resistance has been accompanied by a decline in new drug discovery and an increase in the time to develop a drug from discovery to market. Consequently, drug-resistant pathogens have become a major health threat.

Figure 1-14 Drug-resistant pathogens
Many bacterial pathogens around the world are becoming resistant to antibiotics.
Courtesy of CDC.

Emerging and Reemerging Infectious Diseases

Infectious diseases today have the potential to spread faster and farther. Experts estimate that more than five billion people traveled by air in 2018. With so many people traveling globally, a human disease outbreak or epidemic in one part of the world is only a few airline hours away from becoming a potentially dangerous threat in another region of the globe. This is only too clear with the COVID-19 pandemic that quickly spread worldwide to Europe and North America. Moreover, trade in commodities and animals is happening at a faster pace. If these goods or animals carry disease, the pathogens also are transported. Health experts report that almost 75% of newly emerging infectious diseases are spread to humans by animals, Ebola and COVID-19 being two examples. But, no matter how a disease is spread, when introduced to a new location, most humans will be susceptible to infection because they lack immunity to the new pathogen. Therefore, the threat of epidemics and pandemics is ever-present.