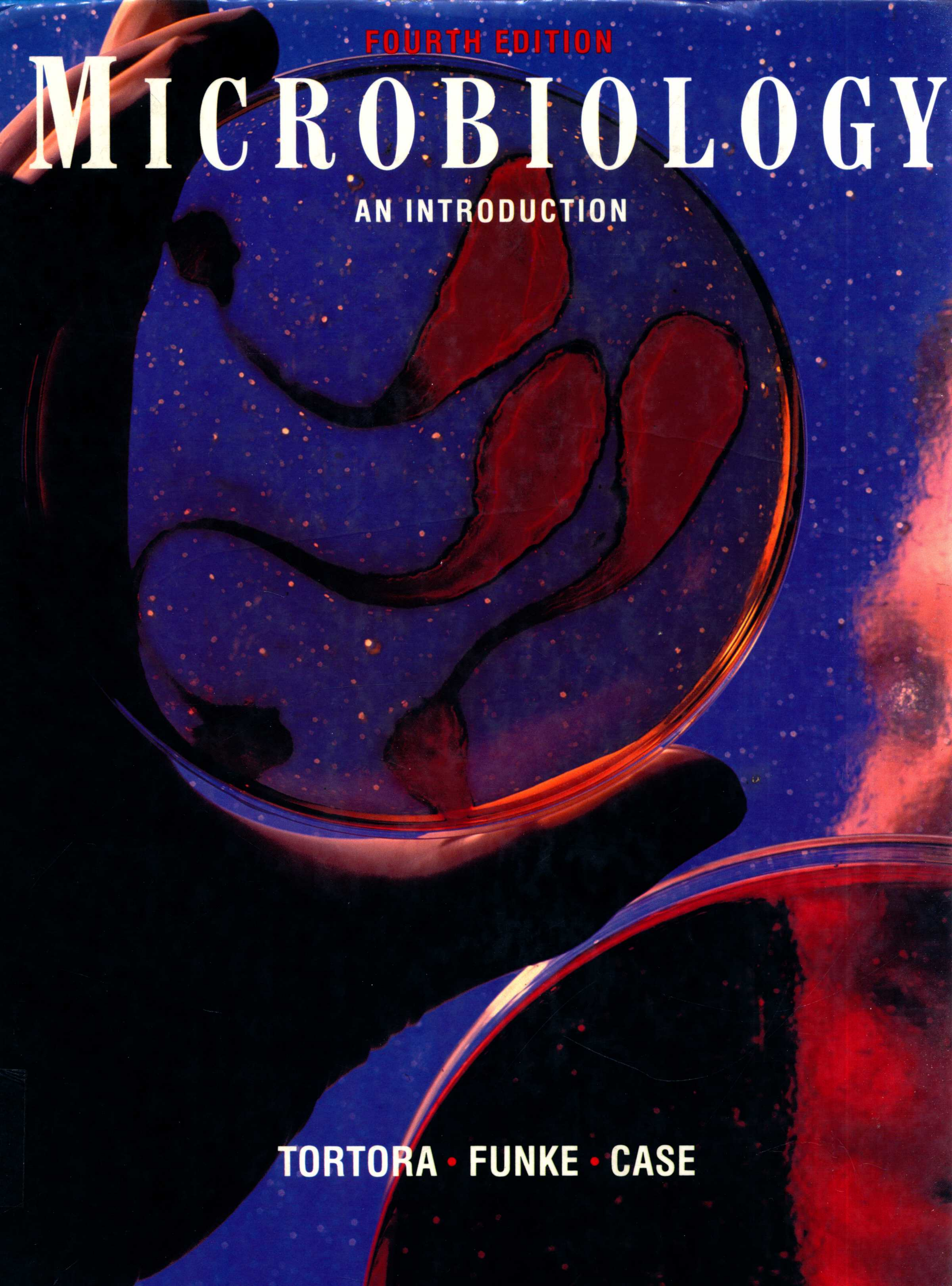
FOURTH EDITION

MICROBIOLOGY

AN INTRODUCTION



TORTORA • FUNKE • CASE

MICROBIOLOGY

An Introduction

FOURTH EDITION

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BERGEN COMMUNITY COLLEGE

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NORTH DAKOTA STATE UNIVERSITY

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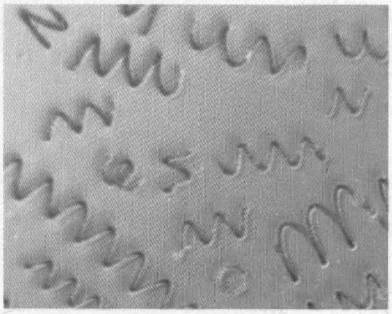

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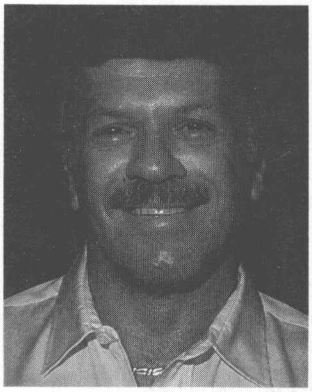
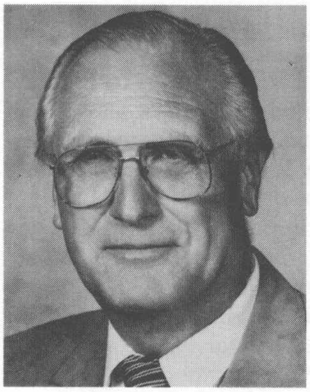


Gerard J. Tortora

Jerry Tortora is a professor of biology and teaches microbiology and human anatomy and physiology at Bergen Community College in Paramus, New Jersey, where he has been a faculty member for the past 24 years. He received his M.A. in biology from Montclair State College in 1965. He belongs to numerous biology/microbiology organizations, such as the American Society of Microbiology (ASM), American Association for the Advancement of Science (AAAS), National Education Association (NEA), New Jersey Education Association (NJEA), and the Metropolitan Association of College and University Biologists (MACUB). Jerry is the author of a number of best-selling biology textbooks.



Berdell R. Funke

Bert Funke received his Ph.D., M.S., and B.S. in microbiology from Kansas State University. He has been a professor of microbiology for 27 years at North Dakota State University. Currently he is teaching microbiology, pathogenic microbiology, food microbiology, and parasitology. Bert is an active member of the ASM and the AAAS. As a research scientist in the Experiment Station at North Dakota State, he has published numerous papers in soil microbiology and food microbiology.

Christine L. Case

Chris Case is a registered microbiologist and a professor of microbiology at Skyline College in San Bruno, California, where she has taught for the past 21 years. She received her Ed.D. in curriculum and instruction from Nova University and her M.A. in microbiology from San Francisco State University. Presently she is an active member of the ASM, the Northern California Association of Microbiologists (NCASM), Northern California Chapter of the Society for Industrial Microbiology (NCA–SIM), and the Scientific Research Society of North America (Sigma Xi). She served as president of NCA–SIM in 1990–91. In addition to teaching, Chris contributes regularly to the professional literature, develops innovative instructional methodologies, and maintains a personal and professional commitment to conservation and the importance of science in society. Chris is also an avid photographer, and many of her photographs appear in this volume.

PREFACE

Microbiology: An Introduction, fourth edition, is a comprehensive text for students in a wide variety of programs, including allied-health sciences, biological sciences, environmental studies, animal science, forestry, agriculture, home economics, and liberal arts. It is a beginning text, assuming no previous study of biology or chemistry.

During the ten years since the publication of the first edition, this book has been used at more than 800 colleges and universities by over 350,000 students. We have been gratified to hear from instructors and students alike that the book has become a favorite among their textbooks—a learning tool that is both effective and enjoyable.

Features of the Revision

Our primary goal for the fourth edition of *Microbiology: An Introduction* was to update the book throughout, making certain it reflects the important new discoveries of the past few years. We also wanted to give our book a fresh look with new photomicrographs, new color illustrations and photographs, and a more inviting design. At the same time, we wanted to maintain a manageable length and the emphasis on the clear coverage of fundamental principles of microbiology. Every page of the book was scrutinized with these goals in mind. The following list highlights the resulting major changes in the fourth edition:

- One of the noticeable changes for this edition is the use of full color for many of the illustrations and photographs. Moreover, many of the illustrations have been redrawn. Color is used in the illustrations to highlight key concepts and to focus attention on the key elements of the discussion. For example, molecules such as DNA and ATP are the same color throughout the book to help students follow pathways and see mechanisms. Colored electron micrographs were selected to highlight structures without distorting natural perspective. Color should help students relate new information to the professional environment by providing accurate examples of organisms and stains.
- A new chapter (Chapter 9) entitled Recombinant DNA and Biotechnology has been added to reflect the increasing importance of this topic, which has been called the technology of the 1990s. This chapter describes the principles employed and their numerous applications and includes many new figures at a level commensurate with the background of the average undergraduate student.
- The immunology chapters (Chapters 17 to 19) have again been thoroughly revised, expanded, and reorganized in response to the many changes that have taken place recently in this dynamic, rapidly evolving field. The discussion of AIDS, for example, has been rewritten in response to current research findings and applications.
- In the chapters dealing with diseases (Chapters 21 to 26), many new photographs have been added, and the majority of these are in color. All discussions of diseases have been carefully scrutinized and updated. The treatment of oral diseases has been expanded greatly, and several new illustrations have been added in response to user comments.
- Many of the MMWR and Microbiology in the News boxes have been replaced with more timely articles. Microbiology Highlights boxes contain interesting information relevant to the study of microbiology that we hope will further motivate students.
- Chapter 5, Microbial Metabolism, has been completely revised to further clarify the basic principles.
- Chapter 8, Microbial Genetics, has been carefully revised to include updated information on molecular biology.

Features Retained from the Earlier Editions

We have retained in this new edition the features that made the previous editions so popular. These include:

- **An appropriate balance between microbiological fundamentals and applications and between medical applications and other applied areas.** As in previous editions, basic principles are given greater emphasis than applications, and health-related applications are emphasized. Applications are integrated throughout the text, and considerable attention is devoted to microorganisms in habitats outside the human body. We hope that all students will gain an appreciation of the fascinating diversity of microbial life, the central roles of microorganisms in nature, and the importance of microorganisms in our daily lives.

- **An illustration program carefully developed to support the text.** Included are both state-of-the-art electron micrographs that dramatically show microbial structures and light micrographs that more closely resemble what is usually seen in a microbiology laboratory. As with previous editions, quality line drawings support text discussions. In the fourth edition, we have improved many illustrations and added new diagrams to further enhance the visual quality of the text.

- **Straightforward presentation of complex topics.** Each section of the text has been revised with the student in mind to maintain the clarity of explanation for which our book has been known.

- **Phonetic pronunciations.** Throughout the text, phonetic pronunciations are provided in parentheses for the majority of genus and species names for microorganisms. The pronunciations are typically provided at the point where the terms are first introduced. A comprehensive, consolidated list of all phonetic pronunciations cited in the book appears following the Appendices.

- **Several appendices at the end of the book heighten its usefulness.** Appendix A is the Classification of Bacteria According to *Bergey's Manual of Systematic Bacteriology*. Appendix B, Word Roots Used in Microbiology, provides basic rules of pronunciation and some phonetic pronunciations for genus and species names used in the text. Appendix C is a Most Probable Numbers (MPN) Table, and Appendix D describes Methods for Taking Clinical Samples. Appendix E, Biochemical Pathways, provides more elaborate illustrations of these key biochemical concepts. Appendix F provides background on Exponents, Exponential Notation, Logarithms, and Generation Time. A Glossary following the appendices provides definitions of all important terms used in the text.

Course Sequences

We have organized the book in what we feel is a useful fashion, but we recognize that the material might be effectively presented in a number of alternative sequences. For those who wish to follow another sequence, we have made each chapter as independent as possible and have included numerous cross-references. Thus, the Survey of the Microbial World, Part Two, could be studied at the beginning of a course, immediately after Chapter 1. Applied Microbiology and the Environment, Part Five, could follow Parts One and Two. Or, Chapter 8, Microbial Genetics, and Chapter 9, Recombinant DNA and Biotechnology, can be covered with Part Five. Since Chapters 7 and 20 both deal with the control of microbial growth, they could be covered together. The material on Microorganisms and Human Disease, Part Four, readily lends itself to rearrangement or selective coverage. The various diseases are organized into chapters according to the host organ-system affected. The *Instructor's Guide* provides detailed guidelines for organizing the disease material in several alternative ways.

Supplementary Materials

All the ancillaries to the text have been revised by their original authors:

- ***Study Guide***

  The *Study Guide*, by Berdell Funke, will help students master and review major concepts and facts from the text. Each chapter of the *Study Guide* begins with a chapter summary organized by the text headings. Important terms are printed in boldface type and are defined, and important figures and tables from the text are included. Following the summary is an extensive self-testing section containing matching questions, fill-in questions, and an answer key.

- ***Instructor's Guide***

  The *Instructor's Guide*, by Christine Case, includes many practical suggestions for using the text in a course. Suggested course outlines and corresponding text pages provide maximum flexibility in organizing your course. Important fourth edition changes are highlighted for each chapter to facilitate the transition from the third to the fourth edition. Also included are answers to study questions from the text. Special case studies of clinical issues ask students to be "medical detectives" by solving the problem presented.

- ***Software***

  Benjamin/Cummings Testing Software is available for IBM PC and Macintosh personal computers.

- ***Transparencies***

  Acetate overhead transparencies of 200 two-color and full-color line drawings from the text are available from the publisher to qualified adopters.

- ***Transparency Masters***

  Transparency masters for all the line drawings from the text are available in a reproducible format from the publisher to qualified adopters.

- ***Slides***

  Two slide sets to complement instructors' lectures are available to qualified adopters. The topics of the slide sets are (1) Microbial Agents of Disease and (2) Human Immunodeficiency Virus.

- *Lab Manual*
  Laboratory Experiments in Microbiology: Brief Edition (third edition, 1992), by Ted Johnson and Christine Case, is a very successful lab manual that has been updated throughout with new exercises on genetic engineering, transformation, bioremediation, and new safety guidelines for the handling of blood and body fluids according to CDC guidelines. The manual is organized so that lab report forms immediately follow each exercise. A detailed *Instructor's Guide* for the lab manual facilitates preparation for laboratory sessions.

Acknowledgments

In the preparation of this textbook, we have benefited from the guidance and advice of a large number of microbiology instructors across the country. R.L. Bernstein, San Francisco State University, provided an early draft of Chapter 9, Recombinant DNA and Biotechnology, and many hours of content expertise. Many dedicated teachers participated in focus groups to help plan the revision. Reviewers offered constructive criticism and valuable suggestions at various stages of manuscript preparation. Contributors, focus group attendees, and reviewers are listed on the following pages. We gratefully acknowledge our debt to these individuals.

We offer special thanks to the staff at Benjamin/Cummings for their dedication to excellence. Shelley Parlante's careful attention to detail served to keep information clear. The scientific and editorial contributions of Jane Reece were invaluable. Larry Olsen and Brian Jones expertly guided our book through the production process. Edith Beard Brady, our sponsoring editor, and Cecilia Mills, our photo editor, were instrumental throughout the revision process. And, we have enduring appreciation for our students, whose comments and suggestions both provide insight and remind us of their needs. This text is for them.

Gerard J. Tortora
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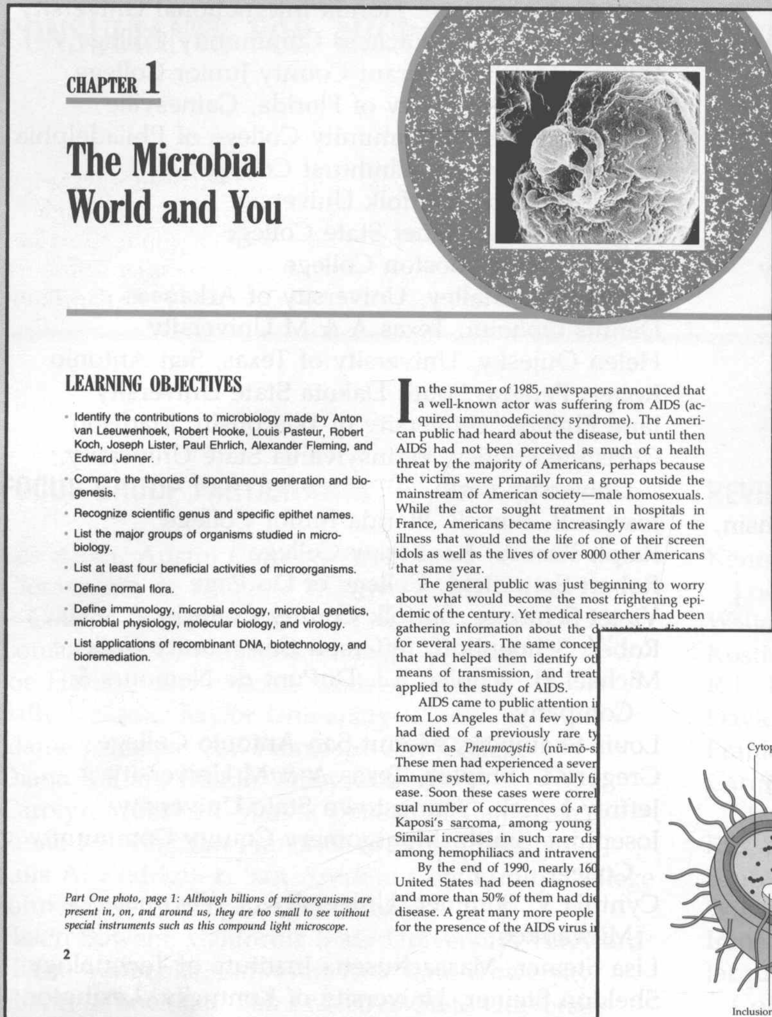
A Student's Guide to Microbiology



CHAPTER 1

The Microbial World and You

LEARNING OBJECTIVES

- Identify the contributions to microbiology made by Anton van Leeuwenhoek, Robert Hooke, Louis Pasteur, Robert Koch, Joseph Lister, Paul Ehrlich, Alexander Fleming, and Edward Jenner.
- Compare the theories of spontaneous generation and biogenesis.
- Recognize scientific genus and specific epithet names.
- List the major groups of organisms studied in microbiology.
- List at least four beneficial activities of microorganisms.
- Define normal flora.
- Define immunology, microbial ecology, microbial genetics, microbial physiology, molecular biology, and virology.
- List applications of recombinant DNA, biotechnology, and bioremediation.

In the summer of 1985, newspapers announced that a well-known actor was suffering from AIDS (acquired immunodeficiency syndrome). The American public had heard about the disease, but until then AIDS had not been perceived as much of a health threat by the majority of Americans, perhaps because the victims were primarily from a group outside the mainstream of American society—male homosexuals. While the actor sought treatment in hospitals in France, Americans became increasingly aware of the illness that would end the life of one of their screen idols as well as the lives of over 8000 other Americans that same year.

The general public was just beginning to worry about what would become the most frightening epidemic of the century. Yet medical researchers had been gathering information about the d[...] for several years. The same concep[...] that had helped them identify ot[...] means of transmission, and treat[...] applied to the study of AIDS.

AIDS came to public attention i[...] from Los Angeles that a few youn[...] had died of a previously rare ty[...] known as *Pneumocystis* (nü-mō-s[...] These men had experienced a sever[...] immune system, which normally fi[...] ease. Soon these cases were correl[...] sual number of occurrences of a ra[...] Kaposi's sarcoma, among young [...] Similar increases in such rare dis[...] among hemophiliacs and intraven[...]

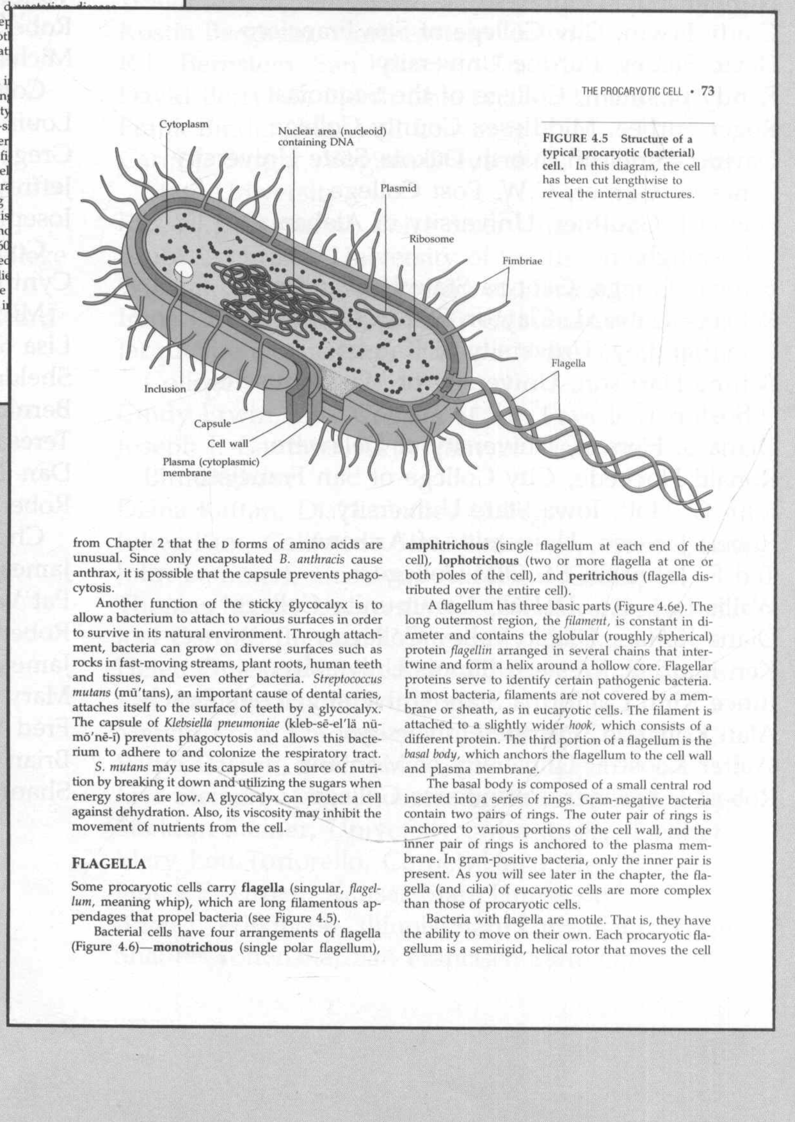
By the end of 1990, nearly 160[...] United States had been diagnose[...] and more than 50% of them had di[...] disease. A great many more people [...] for the presence of the AIDS virus i[...]

Part One photo, page 1: Although billions of microorganisms are present in, on, and around us, they are too small to see without special instruments such as this compound light microscope.

2

Learning objectives open each chapter
Each chapter begins with learning objectives, directing the student to the chapter's important points for mastery.

The authors effectively use examples throughout the text to illustrate the study of microorganisms. Chapter 1, for example, begins with a discussion of the impact of AIDS during the past decade as an example of how microorganisms affect our lives and what microbiologists do.



THE PROCARYOTIC CELL • 73

FIGURE 4.5 Structure of a typical procaryotic (bacterial) cell. In this diagram, the cell has been cut lengthwise to reveal the internal structures.

from Chapter 2 that the D forms of amino acids are unusual. Since only encapsulated *B. anthracis* cause anthrax, it is possible that the capsule prevents phagocytosis.

Another function of the sticky glycocalyx is to allow a bacterium to attach to various surfaces in order to survive in its natural environment. Through attachment, bacteria can grow on diverse surfaces such as rocks in fast-moving streams, plant roots, human teeth and tissues, and even other bacteria. *Streptococcus mutans* (mū'tans), an important cause of dental caries, attaches itself to the surface of teeth by a glycocalyx. The capsule of *Klebsiella pneumoniae* (kleb-sē-el'lä nü-mō'nē-ī) prevents phagocytosis and allows this bacterium to adhere to and colonize the respiratory tract.

S. mutans may use its capsule as a source of nutrition by breaking it down and utilizing the sugars when energy stores are low. A glycocalyx can protect a cell against dehydration. Also, its viscosity may inhibit the movement of nutrients from the cell.

FLAGELLA

Some procaryotic cells carry **flagella** (singular, *flagellum*, meaning whip), which are long filamentous appendages that propel bacteria (see Figure 4.5).

Bacterial cells have four arrangements of flagella (Figure 4.6)—**monotrichous** (single polar flagellum), **amphitrichous** (single flagellum at each end of the cell), **lophotrichous** (two or more flagella at one or both poles of the cell), and **peritrichous** (flagella distributed over the entire cell).

A flagellum has three basic parts (Figure 4.6e). The long outermost region, the *filament*, is constant in diameter and contains the globular (roughly spherical) protein *flagellin* arranged in several chains that intertwine and form a helix around a hollow core. Flagellar proteins serve to identify certain pathogenic bacteria. In most bacteria, filaments are not covered by a membrane or sheath, as in eucaryotic cells. The filament is attached to a slightly wider *hook*, which consists of a different protein. The third portion of a flagellum is the *basal body*, which anchors the flagellum to the cell wall and plasma membrane.

The basal body is composed of a small central rod inserted into a series of rings. Gram-negative bacteria contain two pairs of rings. The outer pair of rings is anchored to various portions of the cell wall, and the inner pair of rings is anchored to the plasma membrane. In gram-positive bacteria, only the inner pair is present. As you will see later in the chapter, the flagella (and cilia) of eucaryotic cells are more complex than those of procaryotic cells.

Bacteria with flagella are motile. That is, they have the ability to move on their own. Each procaryotic flagellum is a semirigid, helical rotor that moves the cell

Text and illustrations are fully integrated
The integration of text and illustrations is a key to the success of *Microbiology: An Introduction*, fourth edition. These pages from Chapter 4 highlight the illustration program. Notice the clearly rendered diagram in Figure 4.5 with key structures labeled and in color. The procaryotic cell reappears in Figure 4.6 as an orienting figure.

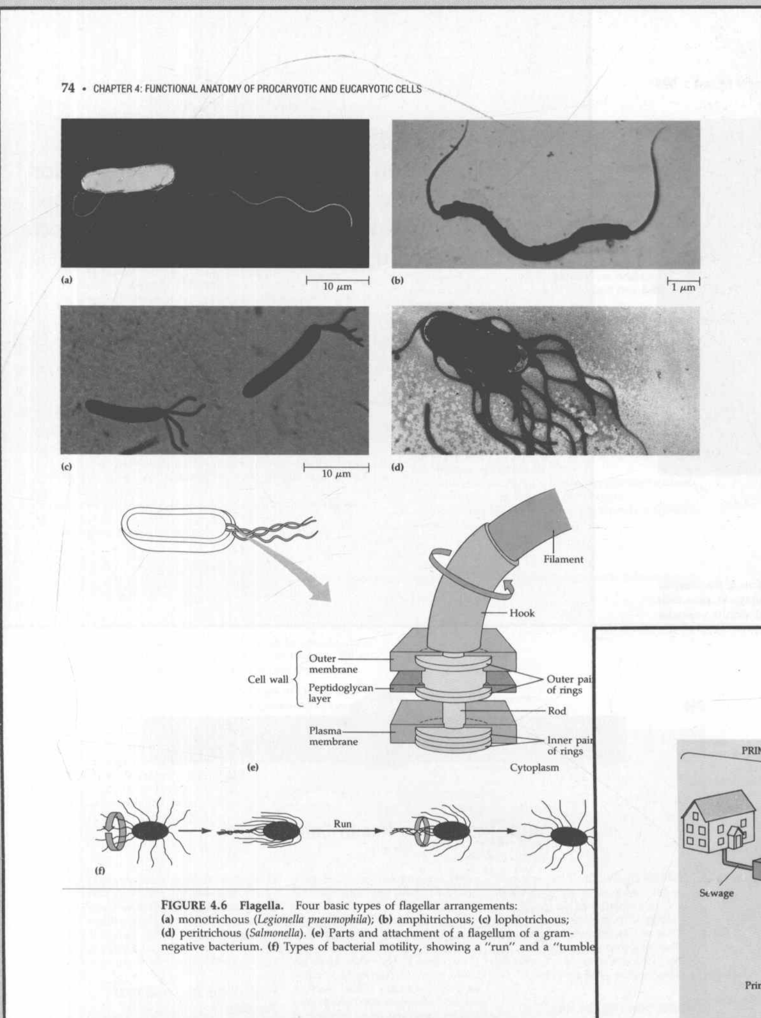

74 • CHAPTER 4: FUNCTIONAL ANATOMY OF PROCARYOTIC AND EUCARYOTIC CELLS

FIGURE 4.6 Flagella. Four basic types of flagellar arrangements: (a) monotrichous (*Legionella pneumophila*); (b) amphitrichous; (c) lophotrichous; (d) peritrichous (*Salmonella*). (e) Parts and attachment of a flagellum of a gram-negative bacterium. (f) Types of bacterial motility, showing a "run" and a "tumble

Text and illustrations are fully integrated
Figure 4.6: The color photographs (a) through (d) illustrate examples of the flagellum structure diagrammed in part (e). Note the orientation diagram. Part (f) shows the use of the flagellum.

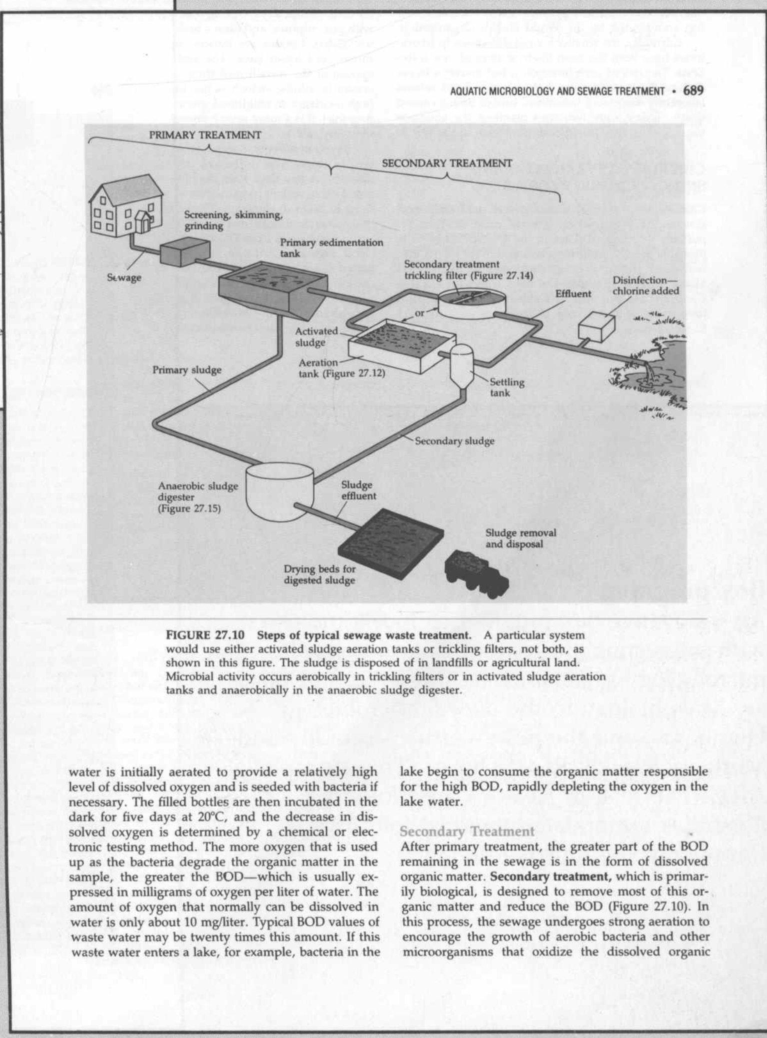

AQUATIC MICROBIOLOGY AND SEWAGE TREATMENT • 689

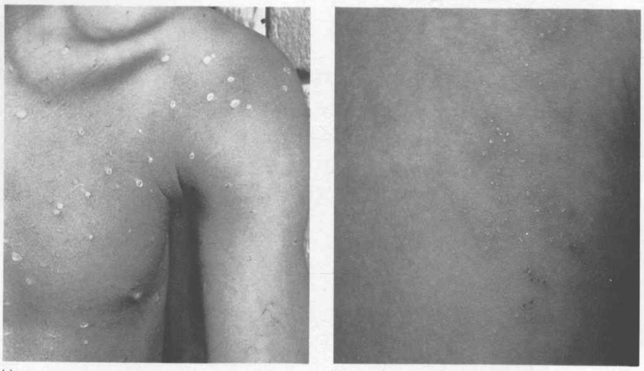
FIGURE 27.10 Steps of typical sewage waste treatment. A particular system would use either activated sludge aeration tanks or trickling filters, not both, as shown in this figure. The sludge is disposed of in landfills or agricultural land. Microbial activity occurs aerobically in trickling filters or in activated sludge aeration tanks and anaerobically in the anaerobic sludge digester.

water is initially aerated to provide a relatively high level of dissolved oxygen and is seeded with bacteria if necessary. The filled bottles are then incubated in the dark for five days at 20°C, and the decrease in dissolved oxygen is determined by a chemical or electronic testing method. The more oxygen that is used up as the bacteria degrade the organic matter in the sample, the greater the BOD—which is usually expressed in milligrams of oxygen per liter of water. The amount of oxygen that normally can be dissolved in water is only about 10 mg/liter. Typical BOD values of waste water may be twenty times this amount. If this waste water enters a lake, for example, bacteria in the lake begin to consume the organic matter responsible for the high BOD, rapidly depleting the oxygen in the lake water.

Secondary Treatment
After primary treatment, the greater part of the BOD remaining in the sewage is in the form of dissolved organic matter. **Secondary treatment,** which is primarily biological, is designed to remove most of this organic matter and reduce the BOD (Figure 27.10). In this process, the sewage undergoes strong aeration to encourage the growth of aerobic bacteria and other microorganisms that oxidize the dissolved organic

Color supports the learning process
The illustration program includes many step-by-step diagrams that help the reader understand important processes. This example from Chapter 27 illustrates the steps in sewage waste treatment.

A Student's Guide to Microbiology



(a) (b)

FIGURE 21.8 Typical lesions associated with (a) chickenpox and (b) shingles (herpes zoster), shown affecting the back of this patient.

The eradication of smallpox was possible because there are no animal host reservoirs for the disease. Once an effective vaccine became available, eradication was accomplished by a concerted vaccination effort coordinated by the World Health Organization.

Currently, the smallpox virus collections in laboratories have been the most likely sources of new infections. The risk of such infection is not merely a hypothetical concern as there have already been several laboratory-associated infections, one of which caused death. Today, only two sites maintain the smallpox virus, one in the United States and one in the USSR.

CHICKENPOX (VARICELLA) AND SHINGLES (HERPES ZOSTER)

Chickenpox (varicella) is a relatively mild childhood disease. After gonorrhea, it is the most common reportable infectious disease in the United States. It is probably greatly underreported, and more than 2 million cases probably occur each year in the United States. Disease summaries of the Centers for Disease Control show that about 100 deaths per year, usually from encephalitis (infection of the brain), are attributed to chickenpox.

Chickenpox is acquired by infection of the respiratory system, and the infection localizes in skin cells after about two weeks. The infected skin is vesicular
for three to four days. During that t
with pus, rupture, and form a scab
ure 21.8a). Lesions are mostly co
throat, and lower back. The vesi
appear in the mouth and throat.
occurs in adults—which is not fr
high incidence in childhood grant
persons—it is a more severe diseas
mortality rate.

Reye's syndrome is an occasio
tion of chickenpox, influenza, an
diseases. A few days after the init
ceded, the patient persistently v
signs of brain dysfunction. Coma,
of the liver, and death can follow.
age in survivors is from brain swell
blood circulation. At one time, th
ported cases approached 90%, bu
declining with improved care and i
when the disease is recognized a
Reye's syndrome affects children a
exclusively. The use of aspirin to lo

New color photographs are effective

The illustration program for the fourth edition includes many new full-color photographs to enable the reader to better visualize the effects of diseases caused by microbes.

MMWR

MORBIDITY AND MORTALITY WEEKLY REPORT

AIDS: The Risk to Health Care Workers

With the advent of the AIDS epidemic, health care workers are understandably concerned about the risk of contracting AIDS after exposure to body fluids of infected patients. However, when precautions are observed, the risk to workers is very small, even for those treating AIDS patients.

Understanding the Risk

The first protection for health care workers is a clear understanding of how AIDS can (and cannot) be transmitted in the course of their work. To date, direct inoculation of infected material is the only proven method of transmission in the health care environment. Infected materials that can transmit AIDS are blood, semen, vaginal secretions, and breast milk. The most common route of transmission is through accidental needle sticks. However, inoculation is also possible if infected material contacts mucous membranes or a break in the health care worker's skin. There is no evidence of HIV transmission by aerosols, the fecal-oral route, mouth-to-mouth or casual contact, or via environmental surfaces such as floors, walls, chairs, and toilets. Saliva, tears, cerebrospinal fluid, amniotic fluid, and urine do not pose the same risk as other body fluids.

The number of health care workers who have become infected and the sources of their infections are being carefully monitored by the CDC. In the United States, by the end of 1990, 37 health care workers who denied other risk factors and who were exposed to blood from patients with HIV had contracted HIV infections, 29 of these following needlestick injuries. Six cases had extensive contact with blood of infected patients and did not observe routine barrier precautions. Additionally, two workers in industrial laboratories producing large quantities of highly concentrated HIV have been reported to have laboratory-acquired HIV infections.

In addition to monitoring all health care workers who have actually contracted HIV, the CDC and others also study workers who have been exposed to infected materials, to determine the magnitude of risk. The largest study followed 4000 health care workers who had been exposed to HIV, 1200 by needlesticks. The study found that the probability of infection following a needlestick injury with blood containing HIV is 0.4%. The probability of infection from mucous membrane exposure to blood is 10 times lower. The probability of acquiring hepatitis B from a needlestick injury with blood containing HBV is from 6 to 30%.

Precautions

In 1985, the CDC developed the strategy of "universal precautions," which should be followed in **all** health care settings. These are:

Gloves. Disposable gloves should be used for direct exposure to infected blood, other body fluids, and tissues. Double-gloving is recommended during invasive surgical procedures. Personnel should not work when they have open skin lesions, weeping dermatitis, or cutaneous wounds.

Gowns, Masks, and Goggles. Masks and protective eyewear are recommended when splashes are expected, such as during airway manipulation, endoscopy, and dental procedures, and in the laboratory.

Needles. To minimize the risk of needle sticks, needles should not be resheathed and should be put in a puncture-proof container for sterilization and disposal.

Disinfection. Routine housekeeping in health care settings should include washing floors, walls, and other areas not normally associated with disease transmissions with 1:100 dilution of household bleach. A 1:10 dilution is recommended for disinfecting a spill.

Prophylactic Treatment After Exposure

Avoidance of exposure is the health care worker's first line of defense. Admittedly, however, accidental exposure cannot always be prevented. Promising new evidence points to the possibility that exposed persons may be able to reduce their risk by prophylactic use of AZT. The National Institutes of Health and the University of California at San Francisco are developing recommendations for use of AZT.

The Risk to Patients

Transmission of HBV and HIV from health care workers to patients during invasive dental procedures (tooth extractions) has been documented. Restrictions on the procedures that can be performed by health care workers with HIV infection have also been considered by the American Medical Association, the American Dental Association, the CDC, and other organizations. Their recommendations state that the risk of HIV transmission from health care workers to patients is greatest during invasive procedures and that decisions regarding restriction of patient care by infected workers who perform such procedures should be made on an individual basis.

Adapted from *MMWR* 38/(S-2) (5/12/89); *MMWR* 39(S-6) (6/23/89); *MMWR* 39:489 (7/27/90).

Box program

An innovative box program supports the text with interesting stories and clinical examples of microbiology in action. The three types of boxes are Microbiology in the News, Microbiology Highlights, and the newsworthy Morbidity and Mortality Weekly Report boxes. This example, AIDS: The Risk to Health Care Workers, illustrates the updated material found throughout the fourth edition.

End-of-chapter material reinforces key ideas
Extensive end-of-chapter material supports the text, including a conceptually organized Study Outline, two types of Study Questions, and updated suggestions for Further Reading.

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STUDY OUTLINE

Bacterial Groups (pp. 273–293)

1. *Bergey's Manual* divides bacteria into sections based on Gram-stain reaction, cellular morphology, oxygen requirements, and nutritional properties.
2. In some cases, the sections include families and orders, and some bacteria are included as genera of uncertain affiliation.
3. Spirochetes are long, thin, helical cells that move by means of an axial filament.
4. Aerobic/microaerophilic, motile, helical/vibrioid gram-negative bacteria move by means of one or more polar flagella.
5. Gram-negative aerobic rods and cocci have polar flagella, if flagellated, and can utilize a wide variety of organic compounds.
6. Facultatively anaerobic gram-negative rods have flagella, if motile, and include the enterics, Vibrionaceae, Pasteurellaceae, and the genus *Gardnerella*.
7. Members of the anaerobic gram-negative straight, curved, and helical rods can be found in humans.
8. Dissimilatory sulfate-reducing or sulfur-reducing bacteria are anaerobes that are important in the sulfur cycle.
9. Anaerobic gram-negative cocci are normal flora of the human mouth.
10. Rickettsias and chlamydias are obligate intracellular parasites.
11. Mycoplasmas are bacteria that lack cell walls.
12. Gram-positive cocci include the catalase-positive *Staphylococcus* and catalase-negative *Streptococcus*.
13. Endospore-forming gram-positive rods and cocci may be aerobic, facultatively anaerobic, or anaerobic.
14. The diverse group of regular, nonsporing, gram-positive rods includes *Lactobacillus* and *Listeria*.
15. Irregular, nonsporing, gram-positive rods include the irregular-staining corynebacteria.
16. Pathogenic species of mycobacteria are acid-fast.
17. Nocardioform bacteria may be acid-fast; they form short filaments.
18. Bacteria with unusual morphologies are discussed in this book in terms of the following groups: budding and/or appendaged; gliding, nonfruiting; gliding, fruiting; budding; sheathed.
19. The chemoautotrophic bacteria play important roles in the cycles of elements in the environment.
20. Extreme halophiles, acidophiles, thermophiles, and methane-producing bacteria are included in the archaeobacteria.
21. Photosynthetic purple and green bacteria are included in the group of anoxygenic phototrophic bacteria; they do not produce molecular oxygen.
22. Cyanobacteria produce molecular oxygen during photosynthesis; they are oxygenic phototrophs.
23. Actinomycetes produce mycelia and reproduce by external spores.

STUDY QUESTIONS

Review

1. The following outline is a key that can be used to identify the medically important groups of bacteria. Fill in the name of the group indicated by the key.

Name of Group and Representative Genus

- I. Gram-positive
  - A. Endospore-forming ______
  - B. Nonsporing
    - 1. Cocci ______
    - 2. Rods
      - a. Regular ______
      - b. Irregular ______
      - c. Acid-fast ______
  - C. Mycelium produced
    - 1. Acid-fast ______
    - 2. Produce chains of conidia ______
- II. Gram-negative
  - A. Cells are helical or curved
    - 1. Axial filament ______
    - 2. No axial filament
      - a. Aerobic
      - b. Anaerobic
  - B. Cells are rods or cocci
    - 1. Aerobic, nonfermenting
    - 2. Facultatively anaerobic
    - 3. Anaerobic
  - C. Intracellular parasites
- III. Lacking cell wall

2. Compare and contrast each of the
   - (a) Cyanobacteria and algae
   - (b) Actinomycetes and fungi
   - (c) *Bacillus* and *Lactobacillus*
   - (d) *Pseudomonas* and *Escherichia*
   - (e) *Leptospira* and *Spirillum*
   - (f) *Veillonella* and *Bacteroides*
   - (g) *Rickettsia* and *Chlamydia*
   - (h) *Thermoplasma* and *Mycoplasma*

FURTHER READING • 295

3. Matching:
   - I. Gram-positive
     - A. Nitrogen-fixing
   - II. Gram-negative
     - A. Phototrophic
       - 1. Anoxygenic
       - 2. Oxygenic
     - B. Chemoautotrophic
       - 1. Oxidize inorganics, such as NO_2^-
       - 2. Reduce CO_2 to CH_4
     - C. Chemoheterotrophic
       - 1. Move via a slime layer
       - 2. Form myxospores
       - 3. Reduce sulfate to H_2S
         - a. Anaerobic
         - b. Thermophilic
       - 4. Long filaments, found in sewage
       - 5. Form projections from the cell
   - III. Unusual cell wall (lacking peptidoglycan)

   - (a) Archaeobacteria
   - (b) Cyanobacteria
   - (c) *Cytophaga*
   - (d) *Desulfovibrio*
   - (e) *Frankia*
   - (f) *Hyphomicrobium*
   - (g) Methanogenic bacteria
   - (h) Myxobacteria
   - (i) *Nitrobacter*
   - (j) Purple bacteria
   - (k) *Sphaerotilus*
   - (l) *Sulfolobus*

Challenge

1. Place each section listed in Table 11.1 in the appropriate division:
   - (a) Typical gram-positive
   - (b) Typical gram-negative
   - (c) Wall-less
   - (d) Unusual walls
2. Where are each of the following classified in *Bergey's Manual*? Why are they described more than once?
   - (a) *Gardnerella*
   - (b) Nocardioforms
   - (c) *Halobacterium*
3. Identify the genus that best fits each description given below:
   - (a) This gram-negative genus is well-suited to degrade hydrocarbons in an oil spill.
   - (b) This gram-positive genus presents the greatest source of bacterial damage to the beekeeping industry.
   - (c) This gram-negative genus is most probably able to oxidize arsenic and asbestos compounds and to clean up polluted water.
   - (d) This group can produce a fuel used for home heating and for generating electricity.

FURTHER READING

Balows, A., H.G. Trüper, M. Dworkin, W. Harder, and K.H. Schliefer, eds. *The Prokaryotes: A Handbook on the Biology of Bacteria*, 2nd ed., 3 volumes. New York: Springer-Verlag, 1991. Discusses characteristics and provides information on cultivation, isolation, and identification of bacteria.

Baron, E.J., and S.M. Finegold. *Diagnostic Microbiology*, 8th ed. St. Louis: Mosby, 1990. A good reference for procedures used in the clinical microbiology laboratory.

Carr, N.G., and B.A. Whitton. *The Biology of Cyanobacteria. Botanical Monographs*, Vol. 19. Berkeley: University of California Press, 1982. A comprehensive reference on morphology, metabolism, and reproduction of cyanobacteria.

Goodfellow, M., M. Mordarski, and S. Williams. *Biology of the Actinomycetes*. New York: Academic Press, 1984. A survey of the biology, ecology, and pathogenicity of this diverse group of bacteria.

Harwood, C.S., and E. Canale-Parola. "Ecology of spirochetes." *Annual Review of Microbiology* 38:161–192, 1984. Describes the role of spirochetes in decomposition and in their associations with humans and other organisms.

Holt, J.G., ed. *Bergey's Manual of Determinative Bacteriology*, 9th ed. Baltimore: Williams & Wilkins, 1992. The standard reference for identification of bacteria.

Holt, J.G., ed. *Bergey's Manual of Systematic Bacteriology*, 1st ed., 4 volumes. Baltimore: Williams & Wilkins, 1984–1989. These four volumes are the standard reference for identification and classification of bacteria.

Kloos, W.E. "Natural populations of the genus *Staphylococcus*." *Annual Review of Microbiology* 34:559–592, 1980. Illustrates the use of modern technology to determine a species; includes a discussion of staphylococci that live on birds and mammals.

Maniloff, J. "Evolution of wall-less prokaryotes." *Annual Review of Microbiology* 37:477–499, 1983. Mycoplasmas and archaeobacteria are examples in this discussion of evolution; information comes from advances in molecular biology.

Shapiro, J.A. "Bacteria as multicellular organisms." *Scientific American* 258(6):82–89, June 1988. Describes bacterial colonies that function as multicellular organisms.

Starr, M.P., H. Stolp, H.G. Truper, A. Balows, and H.G. Schlegel. *The Prokaryotes: A Handbook on Habitats, Isolation and Identification of Bacteria*, 2nd ed., 2 volumes. New York: Springer-Verlag, 1989. Discusses characteristics and provides information on cultivation, isolation, and identification of bacteria.

BRIEF CONTENTS

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PART TWO

PART THREE

PART FOUR

PART FIVE