

# MICRO BIOLOGY

THIRTEENTH  
EDITION

AN INTRODUCTION

TORTORA  
FUNKE  
CASE



# Brief Contents

## PART ONE Fundamentals of Microbiology

- 1 The Microbial World and You 1
- 2 Chemical Principles 24
- 3 Observing Microorganisms Through a Microscope 51
- 4 Functional Anatomy of Prokaryotic and Eukaryotic Cells 72
- 5 Microbial Metabolism 107
- 6 Microbial Growth 151
- 7 The Control of Microbial Growth 178
- 8 Microbial Genetics 204
- 9 Biotechnology and DNA Technology 242

## PART TWO A Survey of the Microbial World

- 10 Classification of Microorganisms 269
- 11 The Prokaryotes: Domains Bacteria and Archaea 295
- 12 The Eukaryotes: Fungi, Algae, Protozoa, and Helminths 323
- 13 Viruses, Viroids, and Prions 361

## PART THREE Interaction between Microbe and Host

- 14 Principles of Disease and Epidemiology 393
- 15 Microbial Mechanisms of Pathogenicity 423
- 16 Innate Immunity: Nonspecific Defenses of the Host 445
- 17 Adaptive Immunity: Specific Defenses of the Host 475
- 18 Practical Applications of Immunology 499
- 19 Disorders Associated with the Immune System 524
- 20 Antimicrobial Drugs 558

## PART FOUR Microorganisms and Human Disease

- 21 Microbial Diseases of the Skin and Eyes 590
- 22 Microbial Diseases of the Nervous System 619
- 23 Microbial Diseases of the Cardiovascular and Lymphatic Systems 650
- 24 Microbial Diseases of the Respiratory System 688
- 25 Microbial Diseases of the Digestive System 721
- 26 Microbial Diseases of the Urinary and Reproductive Systems 760

## PART FIVE Environmental and Applied Microbiology

- 27 Environmental Microbiology 786
- 28 Applied and Industrial Microbiology 809

## Exploring the Microbiome

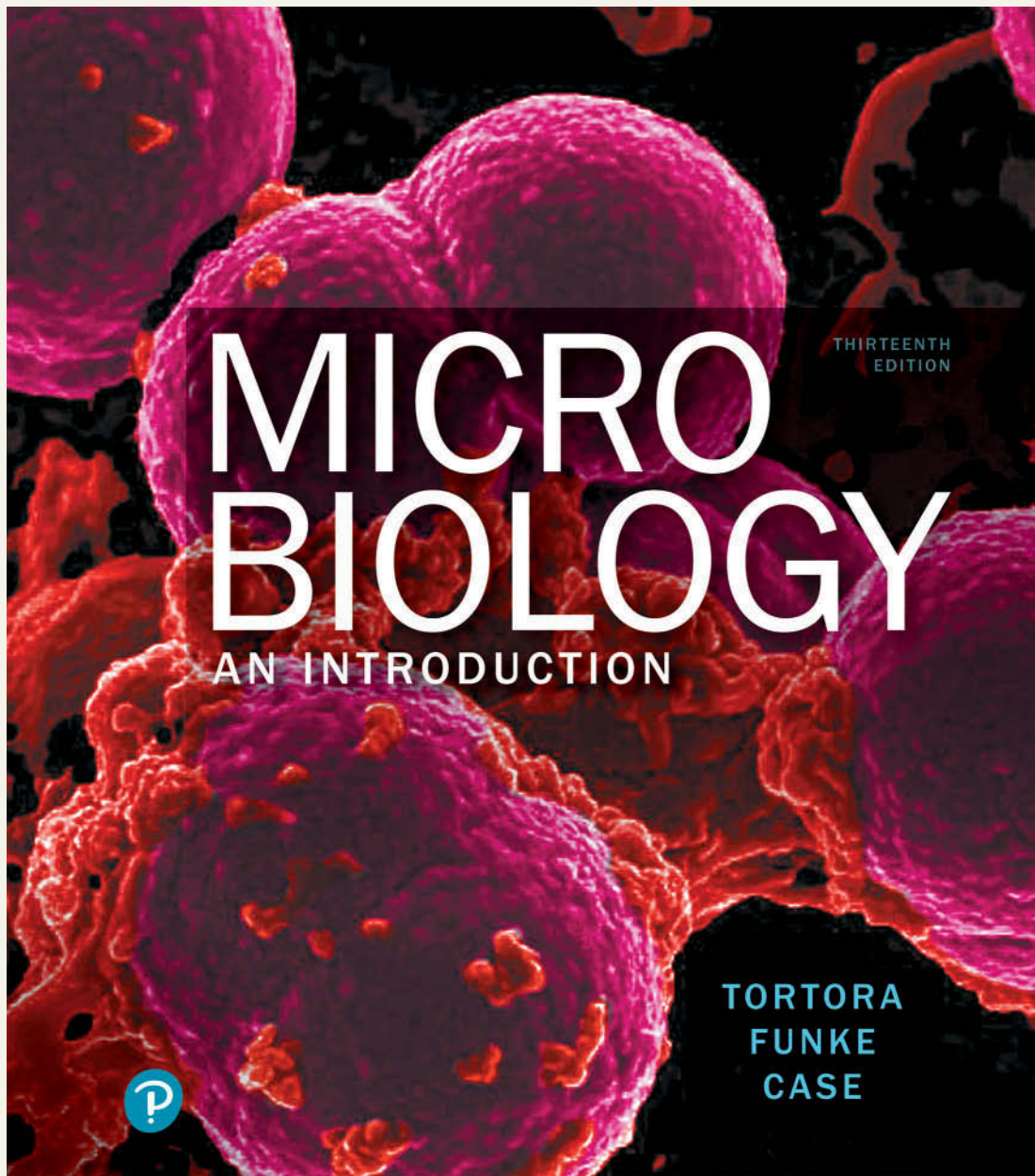
- 1 How Does Your Microbiome Grow? 3
- 2 Feed Our Intestinal Bacteria, Feed Ourselves: A Tale of Two Starches 37
- 3 Obtaining a More Accurate Picture of Our Microbiota 67
- 4 Eukaryotes Are Microbiota, Too 94
- 5 Do Artificial Sweeteners (and the Intestinal Microbiota That Love Them) Promote Diabetes? 132
- 6 Circadian Rhythms and Microbiota Growth Cycles 168
- 7 Antimicrobial Soaps: Doing More Harm Than Good? 191
- 8 Horizontal Gene Transfer and the Unintended Consequences of Antibiotic Usage 230
- 9 Crime Scene Investigation and Your Microbiome 261
- 10 Techniques for Identifying Members of Your Microbiome 291
- 11 Microbiome in Space 320
- 12 The Mycobiome 335
- 13 The Human Virome 364
- 14 Connections between Birth, Microbiome, and Other Health Conditions 395
- 15 Skin Microbiota Interactions and the Making of MRSA 427
- 16 The Microbiome's Shaping of Innate Immunity 452
- 17 The Relationship between Your Immune Cells and Skin Microbiota 491
- 18 Microbiome May Enhance Response to Oral Vaccines 505
- 19 The Link between Blood Type and Composition of the Intestinal Microbiome 532
- 20 Looking to the Microbiome for the Next Great Antibiotic 585
- 21 Normal Skin Microbiota and Our Immune System: Allies in "Skin Wars" 594
- 22 Microbes Impacting the CNS 644
- 23 Is Blood Sterile? 653
- 24 Discovering the Microbiome of the Lungs 691
- 25 Sorting Out Good Neighbors from Bad in the GI Tract 723
- 26 Resident Microbes of the Urinary System 763
- 27 Resident Microbes of Earth's Most Extreme Environments 794
- 28 Using Bacteria to Stop the Spread of Zika Virus 823



All chapter content is tagged to ASM Curriculum Guidelines for Undergraduate Microbiology

# Cutting Edge Microbiology Research for *Today's Learners*

The 13th Edition of Tortora, Funke, and Case's *Microbiology: An Introduction* brings a 21st-century lens to this trusted market-leading introductory textbook. New and updated features, such as **Exploring the Microbiome** boxes and **Big Picture** spreads, emphasize how our understanding of microbiology is constantly expanding. New **In the Clinic Video Tutors** in **Mastering™ Microbiology** illustrate how students can apply their learning to their future careers. Mastering Microbiology also includes new Ready-to-Go Teaching Modules that guide you through the most effective teaching tools available.



# Do your students struggle to make connections between course

**NEW!** Exploring the Microbiome boxes illustrate how research in microbiology is revolutionizing our understanding of health and disease. These boxes highlight the possibilities in this exciting field and present insights into some of the newly identified ways that microbes influence human health. In addition, they provide examples of how research in this field is done—building on existing information, designing fair testing, drawing conclusions, and raising new questions.

## EXPLORING THE MICROBIOME Do Artificial Sweeteners (and the Intestinal Microbiota That Love Them) Promote Diabetes?

For years, beverages made with artificial sweeteners were embraced by diabetics and weight



*Lactobacillus acidophilus*.

watchers because, unlike sugar, artificial sweeteners don't impact blood glucose levels and don't provide calories. However, recent research indicates artificial sweeteners may actually increase the risk of nondiabetics developing the disease. One study published in 2009 by the American Diabetes Association found that daily consumption of diet soda was associated with a 67% greater relative risk of developing type 2 diabetes.

Undigestible by humans, artificial sweeteners provide zero calories to us when we consume them. But they are a great source of nutrients for *Bacteroides* bacteria living in the colon. As *Bacteroides* break down the sweeteners and increase in numbers, other types of microbiota simultaneously decline. Among these are *Lactobacillus* bacteria. Studies indicate that high *Lactobacillus* levels in the intestine are associated with decreased blood sugar levels. The exact mechanism remains unclear, but it is hypothesized that

decreases in the population of *Lactobacillus* bacteria lead to higher blood glucose levels, thereby forcing the body to produce more insulin to control the rising blood glucose. Prolonged high insulin levels may lead to insulin resistance, a condition where the body stops responding correctly to the hormone. Insulin resistance is the hallmark sign of type 2 diabetes.

Recent and current research are exploring whether ingesting probiotics with *Lactobacillus acidophilus* and *Bifidobacterium animalis* may be a useful treatment for type 2 diabetes. Initial studies were promising, showing that these species might lower blood glucose levels. If proven effective, one day bacteria could be key weapons in preventing a deadly disease.

## EXPLORING THE MICROBIOME Antimicrobial Soaps: Doing More Harm Than Good?

*Staphylococcus aureus* is a normal member of the human microbiome, found on the skin and in the nose. *S. aureus* is also a significant cause of healthcare-associated infections in patients. The bacterium can switch from benign member of the skin community to a disease-causing pathogen if it gains entry to the body through a wound.

Since most hospital-acquired *S. aureus* infections are endogenous—that is, caused by bacteria that have colonized in or on the body before someone became a patient—hospitals have long used a disinfectant called triclosan in clinical soaps and skin lotions to prevent staphylococcal infections. Over the years, triclosan was also added to many household products, such as dishwashing detergent, toothpastes, and body washes. However, using these antimicrobial products daily seems to be a case of “too much of a good thing.”

Triclosan enters the blood and is excreted in urine. Therefore, triclosan can be found in many areas of the body,

including the nasal mucosa, of people who use it. The nose is the primary habitat of *S. aureus*. In an example of unintended consequences, presence of triclosan in blood is also associated with nasal colonization of the *S. aureus*. *S. aureus* is more likely to bind to host-cell-membrane proteins in the presence of triclosan. Moreover, constant exposure to triclosan selects for triclosan-resistant mutants over generations of bacterial growth.

Triclosan-resistant bacteria avoid death by removing the chemical from their cells using transporter proteins. These transporters can also remove some antibiotics from the bacterial cells. Moreover, methicillin-resistant *S. aureus* (MRSA) is more resistant to triclosan than methicillin-sensitive staphylococci.

Starting in late 2016, the Federal Drug Association banned triclosan from over-the-counter consumer washing products. The American Medical Association recommends using plain soap and water and proper handwashing techniques instead—

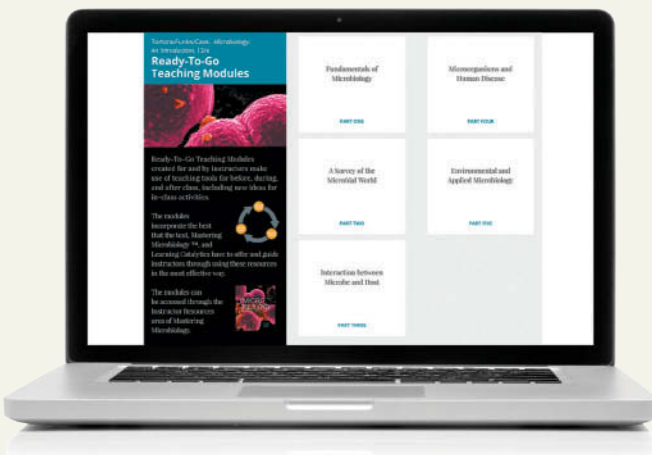
these products and techniques remove microbes without the harmful unintended consequences associated with widespread triclosan use.



*Staphylococcus aureus*.

# content and their future careers?

**New! In the Clinic Video Tutors** bring to life the scenarios in the chapter-opening In the Clinic features. Concepts related to infection control, principles of disease, and antimicrobial therapies are integrated throughout the chapters, providing a platform for instructors to introduce clinically relevant topics throughout the term. Each Video Tutor has a series of assessments assignable in Mastering Microbiology that are tied to learning outcomes.

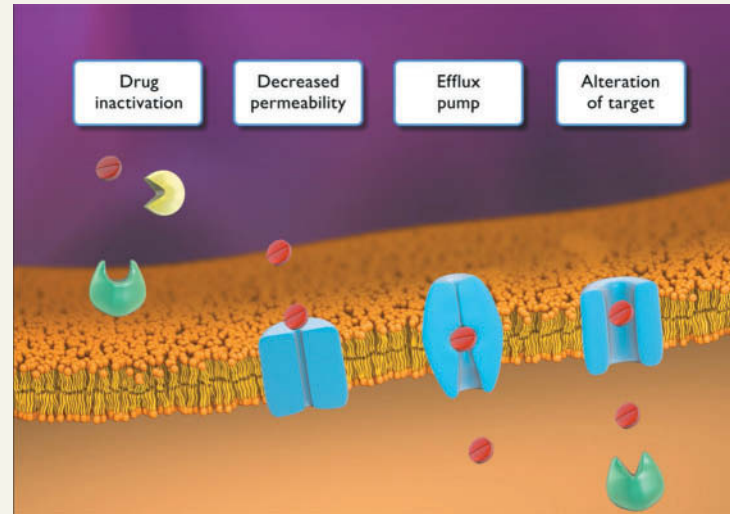


**NEW! Ready-to-Go Teaching Modules** in the Instructor Resources of Mastering Microbiology help instructors efficiently make use of the available teaching tools for the toughest topics in microbiology. Pre-class assignments, in-class activities, and post-class assessments are provided for ease of use.

Within the Ready-to-Go Teaching Modules, **Adopt a Microbe** modules enable instructors to select specific pathogens for additional focus throughout the text.

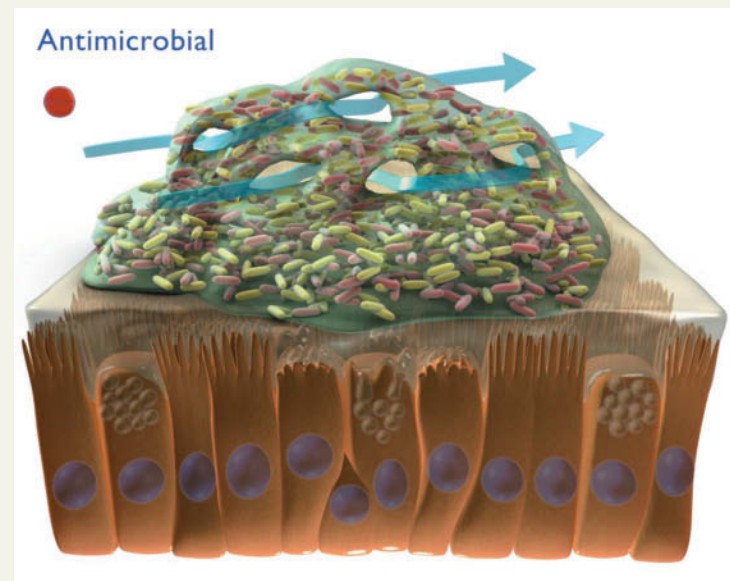
# Do your students need help understanding the toughest

**Interactive Microbiology** is a dynamic suite of interactive tutorials and animations that teach key microbiology concepts. Students actively engage with each topic and learn from manipulating variables, predicting outcomes, and answering assessment questions that test their understanding of basic concepts and their ability to integrate and build on these concepts. These are available in Mastering Microbiology.



**NEW! Even more Interactive Microbiology** modules are available for Fall 2018. Additional titles include:

- Antimicrobial Resistance: Mechanisms
- Antimicrobial Resistance: Selection
- Aerobic Respiration in Prokaryotes
- The Human Microbiome



# concepts in microbiology?

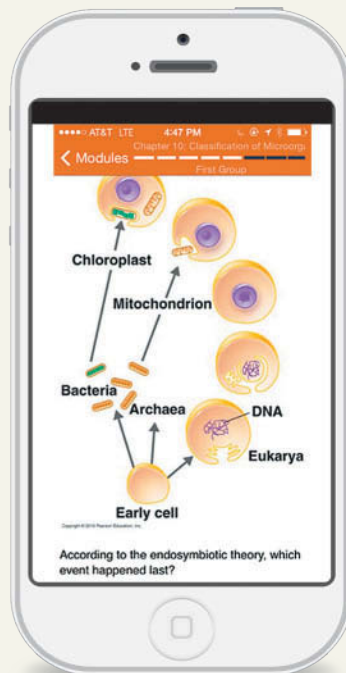
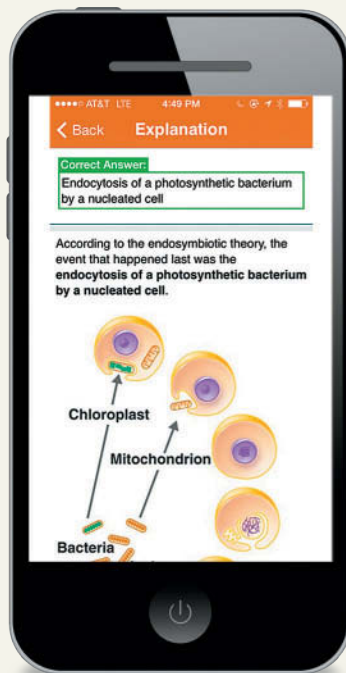
**MicroBoosters** are a suite of brief video tutorials that cover key concepts some students may need to review or relearn. Titles include Study Skills, Math, Scientific Terminology, Basic Chemistry, Cell Biology, and Basic Biology.

**Energy** is the capacity or ability to cause change.

Types of Energy:

1. **Potential energy** — stored energy based on location or structure

*Lowest potential energy state at bottom of slide*



**Dynamic Study Modules** help students acquire, retain, and recall information faster and more efficiently than ever before. The flashcard-style modules are available as a self-study tool or can be assigned by the instructor.

**NEW!** Instructors can now remove questions from **Dynamic Study Modules** to better fit their course.

# Do your students have trouble organizing and synthesizing

**Big Picture** spreads integrate text and illustrations to help students gain a broad, “big picture” understanding of important course topics.

**Each Big Picture spread** includes an overview that **breaks down important concepts** into manageable steps and gives students a clear learning framework for related chapters. Each spread includes Key Concepts that **help students make the connection** between the presented topic and previously learned microbiology principles. Each spread is paired with a coaching activity and assessment questions in Mastering Microbiology.

BIG PICTURE

## Bioterrorism

*Biological agents were first tapped by armies, and now by terrorists. Today, technology and ease of travel increase the potential damage.*

### History of Bioweapons

Biological weapons (bioweapons)—pathogens intentionally used for hostile purposes—are not new. The “ideal” bioweapon is one that disseminates by aerosol, spreads efficiently from human to human, causes debilitating disease, and has no readily available treatment.

The earliest recorded use of a bioweapon occurred in 1346 during the Siege of Kaffa, in what is now known as Feodosia, Ukraine. There the Tartar army catapulted their own dead soldiers’ plague-ridden bodies over city walls to infect opposing troops. Survivors from that attack went on to introduce the “Black Death” to the rest of Europe, sparking the plague pandemic of 1348–1350.

In the eighteenth century, blankets contaminated with smallpox were intentionally introduced into Native American populations by the British during the French and Indian War. And during the Sino-Japanese War (1937–1945), Japanese planes dropped canisters of fleas carrying *Yersinia pestis* bacteria, the causative agent of plague, on China. In 1975, *Bacillus anthracis* endospores were accidentally released from a bioweapon production facility in Sverdlovsk.



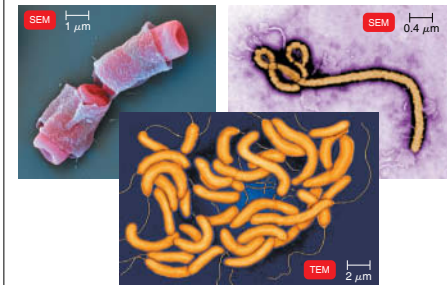
A citadel in Ukraine, location of the first known biowarfare attack in history.

Selected Diseases Identified as Potential Bioweapons	
Bacterial	Viral
Anthrax ( <i>Bacillus anthracis</i> )	Nonbacterial meningitis (Arenaviruses)
Psittacosis ( <i>Chlamydia psittaci</i> )	Hantavirus disease
Botulism ( <i>Clostridium botulinum</i> toxin)	Hemorrhagic fevers (Ebola, Marburg, Lassa)
Tularemia ( <i>Francisella tularensis</i> )	Monkeypox
Cholera ( <i>Vibrio cholerae</i> )	Nipah virus infection
Plague ( <i>Yersinia pestis</i> )	Smallpox

696

### Biological Weapons Banned in the Twentieth Century

The Geneva Conventions are internationally agreed upon standards for conducting war. Written in the 1920s, they prohibited deploying bioweapons—but did not specify that possessing or creating them was illegal. As such, most powerful nations in the twentieth century continued to create bioweapons, and the growing stockpiles posed an ever-growing threat. In 1975, the Biological Weapons Convention banned both possession and development of biological weapons. The majority of the world’s nations ratified the treaty, which stipulated that any existing bioweapons be destroyed and related research halted.



(Clockwise from top left): *Bacillus anthracis*, *Ebolavirus*, and *Vibrio cholerae* are just a few microbes identified as potential bioterrorism agents.

### Emergence of Bioterrorism

Unfortunately, the history of biowarfare doesn’t end with the ratification of the Biological Weapons Convention. Since then, the main actors engaging in biowarfare have not been nations but rather radical groups and individuals. One of the most publicized bioterrorism incidents occurred in 2001, when five people died from, and many more were infected with, anthrax that an army researcher sent through the mail in letters.



Map showing location of 2001 bioterrorism anthrax attacks.



# visual information?



## Public Health Authorities Try to Meet the Threat of Bioterrorism

One of the problems with bioweapons is that they contain living organisms, so their impact is difficult to control or even predict. However, public health authorities have created some protocols to deal with potential bioterrorism incidents.



Biological hazard symbol.

## New Technologies and Techniques to Identify Bioweapons

Monitoring public health, and reporting incidence of diseases of note, is the first step in any bioterrorism defense plan. The faster a potential incident is uncovered, the greater the chance for containment. Rapid tests are being investigated to detect genetic changes in hosts due to bioweapons even before symptoms develop. Early-warning systems, such as DNA chips or recombinant cells that fluoresce in the presence of a bioweapon, are also being developed.



Pro Strips Rapid Screening System, developed by ADVNT Biotechnologies LLC, is the first advanced multi-agent biowarfare detection kit that tests for anthrax, ricin toxin, botulinum toxin, plague, and SEB (staphylococcal enterotoxin B).

## Vaccination: A Key Defense

When the use of biological agents is considered a possibility, military personnel and first responders (health care personnel and others) are vaccinated—if a vaccine for the suspected agent exists. New vaccines are being developed, and existing vaccines are being stockpiled for use where needed.

The current plan to protect civilians in the event of an attack with a microbe is illustrated by the smallpox preparedness plan. This killer disease has been eradicated from the population, but unfortunately, a cache of the virus remains preserved in research facilities, meaning that it might one day be weaponized. It's not practical to vaccinate all people against the disease. Instead, the U.S. government's strategy following a confirmed smallpox outbreak includes "ring containment and voluntary vaccination." A "ring" of vaccinated/protected individuals is built around the bioterrorism infection case and their contacts to prevent further transmission.



Examining mail for *B. anthracis*.

## KEY CONCEPTS

- Vaccination is critical to preventing spread of infectious diseases, especially those that can be weaponized. (See Chapter 18, "Principles and Effects of Vaccinations," pages 500–501.)
- Many organisms that could be used for weapons require BSL-3 facilities. (See Chapter 6, "Special Culture Techniques," pages 161–162.)
- Tracking pathogen genomics provides information on its source. (See Chapter 9, "Forensic Microbiology," pages 258–260.)

Three Big Picture spreads focus on important fundamental topics in microbiology:

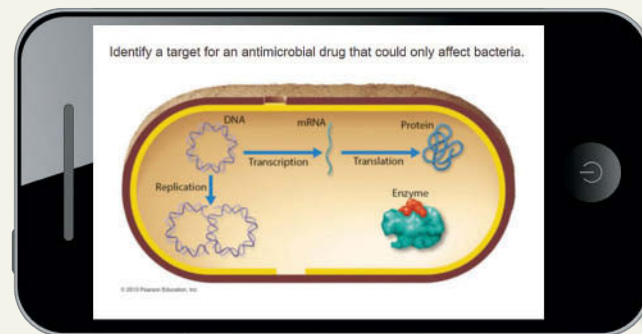
- Metabolism
- Genetics
- Immunity

Eight Big Picture spreads focus on diseases and related public health issues that present complex real-world challenges:

- Vaccine-Preventable Diseases
- The Hygiene Hypothesis
- Neglected Tropical Diseases
- Vertical Transmission: Mother to Child
- Climate Change and Disease
- Bioterrorism
- Cholera After Natural Disasters
- STI Home Test Kits

# Additional Instructor and Student Resources

**Learning Catalytics** is a “bring your own device” (laptop, smartphone, or tablet) student engagement, assessment, and classroom intelligence system. With **Learning Catalytics**, instructors can assess students in real time using open-ended tasks to probe student understanding. Mastering Microbiology users may select from Pearson’s library of questions designed especially for use with **Learning Catalytics**.



## Instructor Resource Materials for *Microbiology: An Introduction*

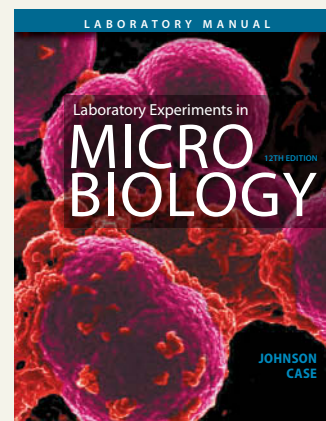
The Instructor Resource Materials organize all instructor media resources by chapter into one convenient and easy-to-use package containing:

- All figures, photos, and tables from the textbook in both labeled and unlabeled formats
- TestGen Test Bank
- MicroFlix animations
- Instructor’s Guide

A wealth of additional classroom resources can be downloaded from the Instructor Resources area of Mastering Microbiology.

## *Laboratory Experiments in Microbiology, 12th Edition* by Johnson/Case

0-134-60520-9 / 978-0-134-60520-3



Engaging, comprehensive and customizable, *Laboratory Experiments in Microbiology* is the perfect companion lab manual for *Microbiology: An Introduction, 13th Edition*.

This page intentionally left blank

# MICRO BIOLOGY

## AN INTRODUCTION

THIRTEENTH EDITION

Gerard J. Tortora

BERGEN COMMUNITY COLLEGE

Berdell R. Funke

NORTH DAKOTA STATE UNIVERSITY

Christine L. Case

SKYLINE COLLEGE

Editor-in-Chief: Serina Beuparlant  
Courseware Portfolio Manager: Jennifer McGill Walker  
Managing Producer: Nancy Tabor  
Content & Design Manager: Michele Mangelli, Mangelli Productions, LLC  
Courseware Director, Content Development: Barbara Yien  
Courseware Sr. Analyst: Erin Strathmann  
Courseware Editorial Assistant: Dapinder Dosanjh  
Rich Media Content Producer: Lucinda Bingham and Tod Regan  
Production Supervisor: Karen Gulliver  
Copyeditor: Sally Peyrefitte  
Proofreaders: Betsy Dietrich and Martha Ghent

Compositor: iEnergizer Aptara®, Ltd  
Art Coordinator: Jean Lake  
Interior & Cover Designer: Hespenheide Design  
Illustrators: Imagineering STA Media Services, Inc.  
Rights & Permissions Management: Ben Ferrini  
Rights & Permissions Project Manager: Cenveo © Publishing Services,  
Matt Perry  
Photo Researcher: Kristin Piljay  
Manufacturing Buyer: Stacey Weinberger  
Director of Product Marketing, Science: Allison Rona

Cover photo: Science Source

Copyright © 2019, 2016, 2013 Pearson Education, Inc. All Rights Reserved. Printed in the United States of America. This publication is protected by copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise. For information regarding permissions, request forms and the appropriate contacts within the Pearson Education Global Rights & Permissions department, please visit [www.pearsoned.com/permissions/](http://www.pearsoned.com/permissions/).

Acknowledgments of third-party content appear on page C-1, which constitutes an extension of this copyright page.

PEARSON, ALWAYS LEARNING, Mastering™ Microbiology, MicroFlix, Interactive Microbiology, and Microboosters, are exclusive trademarks in the U.S. and/or other countries owned by Pearson Education, Inc. or its affiliates.

Unless otherwise indicated herein, any third-party trademarks that may appear in this work are the property of their respective owners and any references to third-party trademarks, logos, or other trade dress are for demonstrative or descriptive purposes only. Such references are not intended to imply any sponsorship, endorsement, authorization, or promotion of Pearson's products by the owners of such marks, or any relationship between the owner and Pearson Education, Inc. or its affiliates, authors, licensees, or distributors.

Trademark attributions are listed on page T-1.

#### Library of Congress Cataloging-in-Publication Data

Names: Tortora, Gerard J., author. | Funke, Berdell R., author. | Case, Christine L., 1948- , author.

Title: Microbiology : an introduction / Gerard J. Tortora, Bergen Community College, Berdell R. Funke, North Dakota State University, Christine L. Case, Skyline College.

Description: Thirteenth edition. | Boston : Pearson, [2019] | Includes bibliographical references and index.

Identifiers: LCCN 2017044147 | ISBN 9780134605180 (student edition) | ISBN 0134605187 (student edition) | ISBN 9780134709260 (instructor's review copy) | ISBN 0134709268 (instructor's review copy)

Subjects: LCSH: Microbiology.

Classification: LCC QR41.2 .T67 2019 | DDC 579--dc23 LC record available at <https://lccn.loc.gov/2017044147>



1 17  
ISBN 10: 0-13-460518-7; ISBN 13: 978-0-13-460518-0 (Student edition)  
ISBN 10: 0-13-470926-8; ISBN 13: 978-0-13-470926-0 (Instructor's Review Copy)

[www.pearson.com](http://www.pearson.com)

## About the Authors



**Gerard J. Tortora** Jerry Tortora is professor of biology and former biology coordinator at Bergen Community College in Paramus, New Jersey. He received his bachelor's degree in biology from Fairleigh Dickinson University and his master's degree in science education from Montclair State College. He has been a member of many professional organizations, including the American Society of Microbiology (ASM), the Human Anatomy and Physiology Society (HAPS), the American

Association for the Advancement of Science (AAAS), the National Education Association (NEA), and the Metropolitan Association of College and University Biologists (MACUB).

Above all, Jerry is devoted to his students and their aspirations. In recognition of this commitment, MACUB presented Jerry with the organization's 1992 President's Memorial Award. In 1995, he was selected as one of the finest faculty scholars of Bergen Community College and was named Distinguished Faculty Scholar. In 1996, he received a National Institute for Staff and Organizational Development (NISOD) excellence award from the University of Texas and was selected to represent Bergen Community College in a campaign to increase awareness of the contributions of community colleges to higher education.

Jerry is the author of several best-selling science textbooks and laboratory manuals, a calling that often requires an additional 40 hours per week beyond his full-time teaching responsibilities. Nevertheless, he still makes time for four or five weekly aerobic workouts. He also enjoys attending opera performances at the Metropolitan Opera House, Broadway plays, and concerts. He spends his quiet time at his beach home on the New Jersey Shore.

To all my children, the most important gift I have: Lynne, Gerard Jr., Kenneth, Anthony, and Drew, whose love and support have been such an important part of my personal life and professional career.



**Berdell R. Funke** Bert Funke received his Ph.D., M.S., and B.S. in microbiology from Kansas State University. He has spent his professional years as a professor of microbiology at North Dakota State University. He taught introductory microbiology, including laboratory sections, general microbiology, food microbiology, soil microbiology, clinical parasitology, and pathogenic microbiology. 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 professor of microbiology at Skyline College in San Bruno, California, where she has taught for the past 46 years. She received her Ed.D. in curriculum and instruction from Nova Southeastern University and her M.A. in microbiology from San Francisco State University. She was Director for the Society for Industrial Microbiology and is an active member of the ASM. She received the ASM and California Hayward outstanding educator awards. Chris received

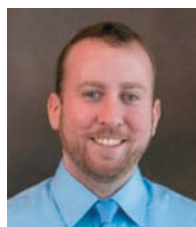
the SACNAS Distinguished Community College Mentor Award for her commitment to her students, several of whom have presented at undergraduate research conferences and won awards. In addition to teaching, Chris contributes regularly to the professional literature, develops innovative educational methodologies, 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 book.

I owe my deepest gratitude to Don Biederman and our three children, Daniel, Jonathan, and Andrea, for their unconditional love and unwavering support.

## Digital Authors



**Warner B. Bair III** Warner Bair is a professor of biology at Lone Star College–CyFair in Cypress, Texas. He has a bachelor of science in general biology and a Ph.D. in cancer biology, both from the University of Arizona. He has over 10 years of higher education teaching experience, teaching both general biology and microbiology classes. Warner is the recipient of multiple educational awards, including the National Institute for Staff and Organizational Development (NISOD) excellence award from the University of Texas and the League for Innovation in the Community College John and Suanne Roueche Excellence Award. Warner has previously authored Interactive Microbiology® videos and activities for the MasteringMicrobiology website and is a member of the American Society for Microbiology (ASM). He is also a certified Instructional Skill Workshop (ISW) facilitator, where he assists other professors in the development of engaging and active classroom instruction. When not working, Warner enjoys outdoor activities and travel. Warner would like to thank his wife, Meaghan, and daughter, Aisling, for their support and understanding of the many late nights and long weekends he spends pursuing his writing.



**Derek Weber** Derek Weber is a professor of biology and microbiology at Raritan Valley Community College in Somerville, New Jersey. He received his B.S. in chemistry from Moravian College and his Ph.D. in biomolecular chemistry from the University of Wisconsin–Madison. His current scholarly work focuses on the use of instructional technology in a flipped classroom to create a more active and engaging learning environment. Derek has received multiple awards for these efforts, including the Award for Innovative Excellence in Teaching, Learning and Technology at the International Teaching and Learning Conference. As part of his commitment to foster learning communities, Derek shares his work at state and national conferences and is a regular attendee at the annual American Society for Microbiology Conference for Undergraduate Educators (ASMCUE). He has previously authored MicroBooster Video Tutorials, available in MasteringMicrobiology, which remediate students on basic concepts in biology and chemistry as they apply to microbiology. Derek acknowledges the support of his patient wife, Lara, and his children, Andrew, James, and Lilly.

# Preface

Since the publication of the first edition nearly 30 years ago, well over 1 million students have used *Microbiology: An Introduction* at colleges and universities around the world, making it the leading microbiology textbook for non-majors. The thirteenth edition continues to be a comprehensive beginning text, assuming no previous study of biology or chemistry. The text is appropriate for students in a wide variety of programs, including the allied health sciences, biological sciences, environmental science, animal science, forestry, agriculture, nutrition science, and the liberal arts.

The thirteenth edition has retained the features that have made this book so popular:

- **An appropriate balance between microbiological fundamentals and applications, and between medical applications and other applied areas of microbiology.** Basic microbiological principles are given greater emphasis, and health-related applications are featured.
- **Straightforward presentation of complex topics.** Each section of the text is written with the student in mind.
- **Clear, accurate, and pedagogically effective illustrations and photos.** Step-by-step diagrams that closely coordinate with narrative descriptions aid student comprehension of concepts.
- **Flexible organization.** We have organized the book in what we think is a useful fashion while recognizing that the material might be effectively presented in other sequences. For instructors who wish to use a different order, we have made each chapter as independent as possible and have included numerous cross-references. The Instructor's Guide provides detailed guidelines for organizing the material in several other ways.
- **Clear presentation of data regarding disease incidence.** Graphs and other disease statistics include the most current data available.
- **Big Picture core topic features.** These two-page spreads focus on the most challenging topics for students to master: metabolism (Chapter 5), genetics (Chapter 8), and immunology (Chapter 16). Each spread breaks down these important concepts into manageable steps and gives students a clear learning framework for the related chapters. Each refers the student to a related MicroFlix video accessible through MasteringMicrobiology.
- **Big Picture disease features.** These two-page spreads appear within each chapter in Part Four, Microorganisms and Human Disease (Chapters 21–26), as well as Chapters 18 (Practical Applications of Immunology) and 19 (Disorders of the Immune System). Each spread focuses on one significant public health aspect of microbiology.

- **ASM guidelines.** The American Society for Microbiology has released six underlying concepts and 27 related topics to provide a framework for key microbiological topics deemed to be of lasting importance beyond the classroom. The thirteenth edition explains the themes and competencies at the beginning of the book and incorporates callouts when chapter content matches one of these 27 topics. Doing so addresses two key challenges: it helps students and instructors focus on the enduring principles of the course, and it provides another pedagogical tool for instructors to assess students' understanding and encourage critical thinking.
- **Cutting-edge media integration.** MasteringMicrobiology ([www.masteringmicrobiology.com](http://www.masteringmicrobiology.com)) provides unprecedented, cutting-edge assessment resources for instructors as well as self-study tools for students. Big Picture Coaching Activities are paired with the book's Core Topics and Clinical Features. Interactive Microbiology is a dynamic suite of interactive tutorials and animations that teach key concepts in microbiology; and MicroBoosters are brief video tutorials that cover key concepts that some students may need to review or relearn.

## New to the Thirteenth Edition

The thirteenth edition focuses on big-picture concepts and themes in microbiology, encouraging students to visualize and synthesize more difficult topics such as microbial metabolism, immunology, and microbial genetics.

The thirteenth edition meets all students at their respective levels of skill and understanding while addressing the biggest challenges that instructors face. Updates to the thirteenth edition enhance the book's consistent pedagogy and clear explanations. Some of the highlights follow.

- **Exploring the Microbiome.** Each chapter has a new box featuring an aspect of microbiome study related to the chapter. Most feature the human microbiome. The boxes are designed to show the importance of microorganisms in health, their importance to life on Earth, and how research on the microbiome is being done.
- **In the Clinic videos accompanying each chapter opener.** In the Clinic scenarios that appear at the start of every chapter include critical-thinking questions that encourage students to think as health care professionals would in various clinical scenarios and spark student interest in the forthcoming chapter content. For the thirteenth edition, videos have been produced for the In the Clinic features for Chapters 1 through 20 and are accessible through MasteringMicrobiology.



- **New Big Picture disease features.** New Big Picture features include Vaccine-Preventable Diseases (Chapter 18), Vertical Transmission: Mother to Child (Chapter 22), and Bioterrorism (Chapter 24).
- **Reworked immunology coverage in Chapters 17, 18, and 19.** New art and more straightforward discussions make this challenging and critical material easier for students to understand and retain.

## Chapter-by-Chapter Revisions

Data in text, tables, and figures have been updated. Other key changes to each chapter are summarized below.

### Chapter 1

- The resurgence in microbiology is highlighted in sections on the Second and Third Golden Ages of Microbiology.
- The Emerging Infectious Diseases section has been updated.
- A discussion of normal microbiota and the human microbiome has been added.

### Chapter 2

- A discussion of the relationship between starch and normal microbiota has been added.

### Chapter 3

- Coverage of super-resolution light microscopy has been added.

### Chapter 4

- The description of the Gram stain method of action has been revised.
- Archaea are now covered.

### Chapter 5

- The potential for probiotic therapy using lactic acid bacteria is introduced.
- Reoxidation of NADH in fermentation is now shown in Figure 5.18.

### Chapter 6

- Discussion has been added regarding the influence of carrying capacity on the stationary phase of microbial growth.
- Discussion of quorum sensing in biofilms is included.
- The plate-streaking figure is revised.

### Chapter 7

- A new section on plant essential oils has been added.

### Chapter 8

- The discussion of operons, induction, and repression has been revised.

- Riboswitches are defined.
- A new box about tracking Zika virus is included.

### Chapter 9

- Discussion of gene editing using CRISPR technology has been added.

### Chapter 10

- Rapid identification using mass spectrophotometry is included.

### Chapter 11

- The genus *Prochlorococcus* is now included.
- The phylum Tenericutes has been added.

### Chapter 12

- The classification of algae and protozoa is updated.

### Chapter 13

- Baltimore classification is included.
- Virusoids are defined.

### Chapter 14

- Discussions of herd immunity and the control of healthcare-associated infections are expanded.
- Clinical trials are defined.
- Congenital transmission of infection is included.
- Discussion of the emerging HAI pathogen *Elizabethkingia* is now included.
- Epidemiological data have been updated.

### Chapter 15

- Genotoxin information is updated.

### Chapter 16

- The discussion of the role of normal microbiota in innate immunity is expanded.
- A table of chemical mediators of inflammation is included.

### Chapter 17

- A new table listing cytokines and their functions has been added.
- Cells involved in cell-mediated immunity are summarized in a table.

### Chapter 18

- Vaccine-preventable diseases are discussed in a new Big Picture.
- Coverage of recombinant vector vaccines has been added.

### Chapter 19

- The discussion of autoimmune diseases has been updated.
- The discussion of HIV/AIDS has been updated.
- The Big Picture box has been revised to expand discussion of dysbiosis-linked disorders.

**Chapter 20**

- Tables have been reorganized.
- Coverage regarding the mechanisms of action of antimicrobial drugs has been updated.
- In the Clinical Focus box, data on antibiotics in animal feed have been updated.

**Chapter 21**

- All data are updated.
- The Big Picture on Neglected Tropical Diseases has been revised to include river blindness.

**Chapter 22**

- All data are updated.
- Coverage of Zika virus disease has been added.
- Discussion of Bell's palsy has been added.
- A new Big Picture covering vertical transmission of congenital infections has been added.

**Chapter 23**

- All data are updated.
- The new species of *Borrelia* are included.
- Maps showing local transmission of vector-borne diseases have been updated.

**Chapter 24**

- All data, laboratory tests, and drug treatments have been updated.
- The emerging pathogen *Enterovirus* D68 is included.
- A new Big Picture covering bioterrorism has been added.

**Chapter 25**

- All data, laboratory tests, and drug treatments are updated.
- *Salmonella* nomenclature has been revised to reflect CDC usage.
- Images of protozoan oocysts and helminth eggs have been added to illustrate laboratory identification.

**Chapter 26**

- All data, laboratory tests, and drug treatments have been updated.
- STIs that do not affect the genitourinary system are cross-referenced to the organ system affected.
- Discussion of ocular syphilis is now included.

**Chapter 27**

- The concept of the Earth microbiome is introduced.
- Discussion of hydrothermal vent communities has been added.
- The discussions of bioremediation of oil and wastewater have been updated.

**Chapter 28**

- The discussion of industrial fermentation has been updated.
- The definition of *biotechnology* is included.
- A discussion of the iChip has been added.
- A table listing fermented foods has been added.
- Discussion of microbial fuel cells is now included.

# Acknowledgments

In preparing this textbook, we have benefited from the guidance and advice of a large number of microbiology instructors across the country. These reviewers have provided constructive criticism and valuable suggestions at various stages of the revision. We gratefully acknowledge our debt to these individuals. Special thanks to retired epidemiologist Joel A. Harrison, Ph.D., M.P.H. for his thorough review and editorial suggestions.

## Contributor

Special thanks to Janette Gomos Klein, *CUNY Hunter College*, for her work on Chapters 17, 18, and 19.

## Reviewers

Jason Adams, *College of DuPage*  
D. Sue Katz Amburn, *Rogers State University*  
Ana Maria Barral, *National University*  
Anar Brahmabhatt, *San Diego Mesa College*  
Carron Bryant, *East Mississippi Community College*  
Luti Erbeznik, *Oakland Community College*  
Tod R. Fairbanks, *Palm Beach State College*  
Myriam Alhadeff Feldman, *North Seattle College*  
Kathleen Finan, *College of DuPage*  
Annissa Furr, *Kaplan University*  
Pattie S. Green, *Tacoma Community College*  
Julianne Grose, *Brigham Young University*  
Amy Jo M. Hammett, *Texas Woman's College*  
Justin Hoshaw, *Waubensee Community College*  
Huey-Jane Liao, *Northern Virginia Community College*  
Anne Montgomery, *Pikes Peak Community College*  
Jessica Parilla, *Georgia State University*  
Taylor Robertson, *Snead State Community College*  
Michelle Scanavino, *Moberly Area Community College*  
John P. Seabolt, *University of Kentucky*  
Ginny Webb, *University of South Carolina Upstate*

We also thank the staff at Pearson Education for their dedication to excellence. Kelsey Churchman guided the early stages of this revision, and Jennifer McGill Walker brought it across the finish line. Erin Strathmann edited the new Exploring the Microbiome boxes, Chapters 17–19, and four new Big Picture spreads. Margot

Otway edited the new In the Clinic videos. Serina Beauparlant and Barbara Yien kept the project moving during a period of staff transitioning.

Michele Mangelli, Mangelli Productions, LLC, managed the book from beginning to end. She expertly guided the team through the editorial phase, managed the new design, and then oversaw the production team and process. Karen Gulliver expertly guided the text through the production process and managed the day-to-day workflow. Sally Peyrefitte's careful attention to continuity and detail in her copyedit of both text and art served to keep concepts and information clear throughout. The talented staff at Imagineering gracefully managed the high volume and complex updates of our art and photo program. Jean Lake coordinated the many complex stages of the art and photo processing and kept the entire art team organized and on-track. Our photo researcher, Kristin Piljay, made sure we had clear and striking images throughout the book. Gary Hespenheide created the elegant interior design and cover. The skilled team at iEnergizer Aptara®, Ltd moved this book through the composition process. Maureen Johnson prepared the index, Betsy Dietrich carefully proofread the art, while Martha Ghent proofread pages. Stacey Weinberger guided the book through the manufacturing process. A special thanks goes to Amy Siegesmund for her detailed review of the pages. Lucinda Bingham, Amanda Kaufmann, and Tod Regan managed this book's robust media program. Courtney Towson managed the print ancillaries through the complex production stages.

Allison Rona, Kelly Galli, and the entire Pearson sales force did a stellar job presenting this book to instructors and students and ensuring its unwavering status as the best-selling microbiology textbook.

We would like to acknowledge our spouses and families, who have provided invaluable support throughout the writing process.

Finally, we have an enduring appreciation for our students, whose comments and suggestions provide insight and remind us of their needs. This text is for them.

Gerard J. Tortora      Berdell R. Funke      Christine Case

# Contents

## PART ONE Fundamentals of Microbiology

### 1 The Microbial World and You 1

#### Microbes in Our Lives 2

The Microbiome

#### Naming and Classifying Microorganisms 4

Nomenclature • Types of Microorganisms • Classification of Microorganisms

#### A Brief History of Microbiology 6

The First Observations • The Debate over Spontaneous Generation • The First Golden Age of Microbiology • The Second Golden Age of Microbiology • The Third Golden Age of Microbiology

#### Microbes and Human Welfare 14

Recycling Vital Elements • Sewage Treatment: Using Microbes to Recycle Water • Bioremediation: Using Microbes to Clean Up Pollutants • Insect Pest Control by Microorganisms • Biotechnology and Recombinant DNA Technology

#### Microbes and Human Disease 16

Biofilms • Infectious Diseases • Emerging Infectious Diseases

#### Study Outline • Study Questions 20

### 2 Chemical Principles 24

#### The Structure of Atoms 25

Chemical Elements • Electronic Configurations

#### How Atoms Form Molecules: Chemical Bonds 27

Ionic Bonds • Covalent Bonds • Hydrogen Bonds • Molecular Mass and Moles

#### Chemical Reactions 30

Energy in Chemical Reactions • Synthesis Reactions • Decomposition Reactions • Exchange Reactions • The Reversibility of Chemical Reactions

#### IMPORTANT BIOLOGICAL MOLECULES 31

##### Inorganic Compounds 31

Water • Acids, Bases, and Salts • Acid–Base Balance: The Concept of pH

##### Organic Compounds 33

Structure and Chemistry • Carbohydrates • Lipids • Proteins • Nucleic Acids • Adenosine Triphosphate (ATP)

#### Study Outline • Study Questions 47

### 3 Observing Microorganisms Through a Microscope 51

#### Units of Measurement 52

#### Microscopy: The Instruments 52

Light Microscopy • Two-Photon Microscopy • Super-Resolution Light Microscopy • Scanning Acoustic Microscopy • Electron Microscopy • Scanned-Probe Microscopy

#### Preparation of Specimens for Light Microscopy 61

Preparing Smears for Staining • Simple Stains • Differential Stains • Special Stains

#### Study Outline • Study Questions 69

### 4 Functional Anatomy of Prokaryotic and Eukaryotic Cells 72

#### Comparing Prokaryotic and Eukaryotic Cells: An Overview 73

#### THE PROKARYOTIC CELL 73

##### The Size, Shape, and Arrangement of Bacterial Cells 73

##### Structures External to the Cell Wall 75

Glycocalyx • Flagella and Archaella • Axial Filaments • Fimbriae and Pili

##### The Cell Wall 80

Composition and Characteristics • Cell Walls and the Gram Stain Mechanism • Atypical Cell Walls • Damage to the Cell Wall

##### Structures Internal to the Cell Wall 85

The Plasma (Cytoplasmic) Membrane • The Movement of Materials across Membranes • Cytoplasm • The Nucleoid • Ribosomes • Inclusions • Endospores

#### THE EUKARYOTIC CELL 94

##### Flagella and Cilia 96

##### The Cell Wall and Glycocalyx 96

##### The Plasma (Cytoplasmic) Membrane 97

##### Cytoplasm 98

##### Ribosomes 98

##### Organelles 98

The Nucleus • Endoplasmic Reticulum • Golgi Complex • Lysosomes • Vacuoles • Mitochondria • Chloroplasts • Peroxisomes • Centrosome

##### The Evolution of Eukaryotes 102

#### Study Outline • Study Questions 103

## 5 Microbial Metabolism 107

**Catabolic and Anabolic Reactions 110**

**Enzymes 111**

- Collision Theory • Enzymes and Chemical Reactions
- Enzyme Specificity and Efficiency • Naming Enzymes
- Enzyme Components • Factors Influencing Enzymatic Activity • Feedback Inhibition • Ribozymes

**Energy Production 117**

- Oxidation-Reduction Reactions • The Generation of ATP
- Metabolic Pathways of Energy Production

**Carbohydrate Catabolism 119**

- Glycolysis • Additional Pathways to Glycolysis • Cellular Respiration • Fermentation

**Lipid and Protein Catabolism 133**

**Biochemical Tests and Bacterial Identification 134**

**Photosynthesis 135**

- The Light-Dependent Reactions: Photophosphorylation
- The Light-Independent Reactions: The Calvin-Benson Cycle

**A Summary of Energy Production Mechanisms 138**

**Metabolic Diversity among Organisms 138**

- Photoautotrophs • Photoheterotrophs • Chemoautotrophs
- Chemoheterotrophs

**Metabolic Pathways of Energy Use 140**

- Polysaccharide Biosynthesis • Lipid Biosynthesis • Amino Acid and Protein Biosynthesis • Purine and Pyrimidine Biosynthesis

**The Integration of Metabolism 143**

**Study Outline • Study Questions 145**

## 6 Microbial Growth 151

**The Requirements for Growth 152**

- Physical Requirements • Chemical Requirements

**Biofilms 157**

**Culture Media 159**

- Chemically Defined Media • Complex Media • Anaerobic Growth Media and Methods • Special Culture Techniques
- Selective and Differential Media • Enrichment Culture

**Obtaining Pure Cultures 163**

**Preserving Bacterial Cultures 164**

**The Growth of Bacterial Cultures 165**

- Bacterial Division • Generation Time • Logarithmic Representation of Bacterial Populations • Phases of Growth
- Direct Measurement of Microbial Growth • Estimating Bacterial Numbers by Indirect Methods

**Study Outline • Study Questions 174**

## 7 The Control of Microbial Growth 178

**The Terminology of Microbial Control 179**

**The Rate of Microbial Death 180**

**Actions of Microbial Control Agents 180**

- Alteration of Membrane Permeability • Damage to Proteins and Nucleic Acids

**Physical Methods of Microbial Control 182**

- Heat • Filtration • Low Temperatures • High Pressure
- Desiccation • Osmotic Pressure • Radiation

**Chemical Methods of Microbial Control 187**

- Principles of Effective Disinfection • Evaluating a Disinfectant
- Types of Disinfectants

**Microbial Characteristics and Microbial Control 198**

**Study Outline • Study Questions 200**

## 8 Microbial Genetics 204

**Structure and Function of the Genetic Material 205**

- Genotype and Phenotype • DNA and Chromosomes • The Flow of Genetic Information • DNA Replication • RNA and Protein Synthesis

**The Regulation of Bacterial Gene Expression 215**

- Pre-transcriptional Control • Post-transcriptional Control

**Changes in Genetic Material 221**

- Mutation • Types of Mutations • Mutagens • The Frequency of Mutation • Identifying Mutants • Identifying Chemical Carcinogens

**Genetic Transfer and Recombination 229**

- Plasmids and Transposons • Transformation in Bacteria
- Conjugation in Bacteria • Transduction in Bacteria

**Genes and Evolution 237**

**Study Outline • Study Questions 238**

## 9 Biotechnology and DNA Technology 242

**Introduction to Biotechnology 243**

- Recombinant DNA Technology • An Overview of Recombinant DNA Procedures

**Tools of Biotechnology 245**

- Selection • Mutation • Restriction Enzymes • Vectors
- Polymerase Chain Reaction

**Techniques of Genetic Modification 248**

- Inserting Foreign DNA into Cells • Obtaining DNA • Selecting a Clone • Making a Gene Product

**Applications of DNA Technology 254**

Therapeutic Applications • Genome Projects • Scientific Applications • Agricultural Applications

**Safety Issues and the Ethics of Using DNA Technology 262**

Study Outline • Study Questions 265

**PART TWO A Survey of the Microbial World****10 Classification of Microorganisms 269****The Study of Phylogenetic Relationships 270**

The Three Domains • A Phylogenetic Tree

**Classification of Organisms 274**

Scientific Nomenclature • The Taxonomic Hierarchy  
• Classification of Prokaryotes • Classification of Eukaryotes  
• Classification of Viruses

**Methods of Classifying and Identifying Microorganisms 277**

Morphological Characteristics • Differential Staining  
• Biochemical Tests • Serology • Phage Typing • Fatty Acid Profiles • Flow Cytometry • DNA Sequencing • DNA Fingerprinting • Nucleic Acid Hybridization • Putting Classification Methods Together

Study Outline • Study Questions 291

**11 The Prokaryotes: Domains Bacteria and Archaea 295****The Prokaryotic Groups 296****DOMAIN BACTERIA 296****Gram-Negative Bacteria 297**

Proteobacteria • The Nonproteobacteria Gram-Negative Bacteria

**The Gram-Positive Bacteria 312**

Firmicutes (Low G + C Gram-Positive Bacteria) • Tenericutes  
• Actinobacteria (High G + C Gram-Positive Bacteria)

**DOMAIN ARCHAEA 318****Diversity within the Archaea 318****MICROBIAL DIVERSITY 319****Discoveries Illustrating the Range of Diversity 319**

Study Outline • Study Questions 321

**12 The Eukaryotes: Fungi, Algae, Protozoa, and Helminths 323****Fungi 324**

Characteristics of Fungi • Medically Important Fungi • Fungal Diseases • Economic Effects of Fungi

**Lichens 335****Algae 337**

Characteristics of Algae • Selected Phyla of Algae • Roles of Algae in Nature

**Protozoa 341**

Characteristics of Protozoa • Medically Important Protozoa

**Slime Molds 346****Helminths 347**

Characteristics of Helminths • Platyhelminths • Nematodes

**Arthropods as Vectors 355**

Study Outline • Study Questions 357

**13 Viruses, Viroids, and Prions 361****General Characteristics of Viruses 362**

Host Range • Viral Size

**Viral Structure 363**

Nucleic Acid • Capsid and Envelope • General Morphology

**Taxonomy of Viruses 366****Isolation, Cultivation, and Identification of Viruses 370**

Growing Bacteriophages in the Laboratory • Growing Animal Viruses in the Laboratory • Viral Identification

**Viral Multiplication 372**

Multiplication of Bacteriophages • Multiplication of Animal Viruses

**Viruses and Cancer 384**

The Transformation of Normal Cells into Tumor Cells  
• DNA Oncogenic Viruses • RNA Oncogenic Viruses • Viruses to Treat Cancer

**Latent Viral Infections 386****Persistent Viral Infections 386****Plant Viruses and Viroids 386****Prions 388**

Study Outline • Study Questions 389

**PART THREE Interaction between Microbe and Host****14 Principles of Disease and Epidemiology 393****Pathology, Infection, and Disease 394****Human Microbiome 394**

Relationships between the Normal Microbiota and the Host  
• Opportunistic Microorganisms • Cooperation among Microorganisms

**The Etiology of Infectious Diseases 398**

Koch's Postulates • Exceptions to Koch's Postulates

**Classifying Infectious Diseases 400**

Occurrence of a Disease • Severity or Duration of a Disease  
• Extent of Host Involvement

**Patterns of Disease 402**

Predisposing Factors • Development of Disease

**The Spread of Infection 403**

Reservoirs of Infection • Transmission of Disease

**Healthcare-Associated Infections (HAIs) 408**

Microorganisms in the Hospital • Compromised Host • Chain of Transmission • Control of Healthcare-Associated Infections

**Emerging Infectious Diseases 411**

**Epidemiology 413**

Descriptive Epidemiology • Analytical Epidemiology  
• Experimental Epidemiology • Case Reporting • The Centers for Disease Control and Prevention (CDC)

Study Outline • Study Questions 418

## 15 Microbial Mechanisms of Pathogenicity 423

**How Microorganisms Enter a Host 424**

Portals of Entry • The Preferred Portal of Entry • Numbers of Invading Microbes • Adherence

**How Bacterial Pathogens Penetrate Host Defenses 427**

Capsules • Cell Wall Components • Enzymes • Antigenic Variation • Penetration into the Host • Biofilms

**How Bacterial Pathogens Damage Host Cells 430**

Using the Host's Nutrients: Siderophores • Direct Damage  
• Production of Toxins • Plasmids, Lysogeny, and Pathogenicity

**Pathogenic Properties of Viruses 436**

Viral Mechanisms for Evading Host Defenses • Cytopathic Effects of Viruses

**Pathogenic Properties of Fungi, Protozoa, Helminths, and Algae 438**

Fungi • Protozoa • Helminths • Algae

**Portals of Exit 440**

Study Outline • Study Questions 441

## 16 Innate Immunity: Nonspecific Defenses of the Host 445

**The Concept of Immunity 448**

**FIRST LINE OF DEFENSE: SKIN AND MUCOUS MEMBRANES 448**

Physical Factors 448

Chemical Factors 450

Normal Microbiota and Innate Immunity 451

**SECOND LINE OF DEFENSE 453**

Formed Elements in Blood 453

The Lymphatic System 455

Phagocytes 456

Actions of Phagocytic Cells • The Mechanism of Phagocytosis

Inflammation 459

Vasodilation and Increased Permeability of Blood Vessels  
• Phagocyte Migration and Phagocytosis • Tissue Repair

Fever 462

Antimicrobial Substances 463

The Complement System • Interferons • Iron-Binding Proteins  
• Antimicrobial Peptides • Other Factors

Study Outline • Study Questions 472

## 17 Adaptive Immunity: Specific Defenses of the Host 475

The Adaptive Immune System 476

Dual Nature of the Adaptive Immune System 476

Overview of Humoral Immunity • Overview of Cellular Immunity

Cytokines: Chemical Messengers of Immune Cells 477

Antigens and Antibodies 478

Antigens • Humoral Immunity: Antibodies

Humoral Immunity Response Process 482

Activation and Clonal Expansion of Antibody-Producing Cells  
• The Diversity of Antibodies

Results of the Antigen–Antibody Interaction 484

Cellular Immunity Response Process 486

Antigen-Presenting Cells (APCs) • Classes of T Cells

Nonspecific Cells and Extracellular Killing by the Adaptive Immune System 492

Immunological Memory 493

Types of Adaptive Immunity 494

Study Outline • Study Questions 496

## 18 Practical Applications of Immunology 499

Vaccines 500

Principles and Effects of Vaccination • Types of Vaccines and Their Characteristics • Vaccine Production, Delivery Methods, and Formulations

**Diagnostic Immunology 507**

- Use of Monoclonal Antibodies • Precipitation Reactions
- Agglutination Reactions • Neutralization Reactions
- Complement-Fixation Reactions • Fluorescent-Antibody Techniques • Enzyme-Linked Immunosorbent Assay (ELISA)
- Western Blotting (Immunoblotting) • The Future of Diagnostic and Therapeutic Immunology

Study Outline • Study Questions 520

## 19 Disorders Associated with the Immune System 524

**Hypersensitivity 525**

- Allergies and the Microbiome • Type I (Anaphylactic) Reactions
- Type II (Cytotoxic) Reactions • Type III (Immune Complex) Reactions • Type IV (Delayed Cell-Mediated) Reactions

**Autoimmune Diseases 536**

- Cytotoxic Autoimmune Reactions • Immune Complex Autoimmune Reactions • Cell-Mediated Autoimmune Reactions

**Reactions to Transplantation 538**

- Immunosuppression to Prevent Transplant Rejection

**The Immune System and Cancer 542**

- Immunotherapy for Cancer

**Immunodeficiencies 543**

- Congenital Immunodeficiencies • Acquired Immunodeficiencies

**Acquired Immunodeficiency Syndrome (AIDS) 544**

- The Origin of AIDS • HIV Infection • Diagnostic Methods
- HIV Transmission • AIDS Worldwide • Preventing and Treating AIDS

Study Outline • Study Questions 554

## 20 Antimicrobial Drugs 558

**The History of Chemotherapy 559**

- Antibiotic Use and Discovery Today

**Spectrum of Antimicrobial Activity 560****The Action of Antimicrobial Drugs 561**

- Inhibiting Cell Wall Synthesis • Inhibiting Protein Synthesis
- Injuring the Plasma Membrane • Inhibiting Nucleic Acid Synthesis • Inhibiting the Synthesis of Essential Metabolites

**Common Antimicrobial Drugs 564**

- Antibacterial Antibiotics: Inhibitors of Cell Wall Synthesis
- Inhibitors of Protein Synthesis • Injury to Membranes
- Nucleic Acid Synthesis Inhibitors • Competitive Inhibition of Essential Metabolites • Antifungal Drugs • Antiviral Drugs
- Antiprotozoan and Antihelminthic Drugs

**Tests to Guide Chemotherapy 577**

- The Diffusion Methods • Broth Dilution Tests

**Resistance to Antimicrobial Drugs 579**

- Mechanisms of Resistance • Antibiotic Misuse • Cost and Prevention of Resistance

**Antibiotic Safety 583****Effects of Combinations of Drugs 583****Future of Chemotherapeutic Agents 583**

Study Outline • Study Questions 586

## PART FOUR Microorganisms and Human Disease

## 21 Microbial Diseases of the Skin and Eyes 590

**Structure and Function of the Skin 591**

- Mucous Membranes

**Normal Microbiota of the Skin 592****Microbial Diseases of the Skin 592**

- Bacterial Diseases of the Skin • Viral Diseases of the Skin
- Fungal Diseases of the Skin and Nails • Parasitic Infestation of the Skin

**Microbial Diseases of the Eye 612**

- Inflammation of the Eye Membranes: Conjunctivitis • Bacterial Diseases of the Eye • Other Infectious Diseases of the Eye

Study Outline • Study Questions 616

## 22 Microbial Diseases of the Nervous System 619

**Structure and Function of the Nervous System 620****Bacterial Diseases of the Nervous System 621**

- Bacterial Meningitis • Tetanus • Botulism • Leprosy

**Viral Diseases of the Nervous System 630**

- Poliomyelitis • Rabies • Arboviral Encephalitis

**Fungal Disease of the Nervous System 638**

- Cryptococcus neoformans* Meningitis (Cryptococcosis)

**Protozoan Diseases of the Nervous System 639**

- African Trypanosomiasis • Amebic Meningoencephalitis

**Nervous System Diseases Caused by Prions 642**

- Bovine Spongiform Encephalopathy and Variant Creutzfeldt-Jakob Disease

**Diseases Caused by Unidentified Agents 645**

Study Outline • Study Questions 647



## 23 Microbial Diseases of the Cardiovascular and Lymphatic Systems 650

Structure and Function of the Cardiovascular and Lymphatic Systems 651

Bacterial Diseases of the Cardiovascular and Lymphatic Systems 652

- Sepsis and Septic Shock • Bacterial Infections of the Heart
- Rheumatic Fever • Tularemia • Brucellosis (Undulant Fever)
- Anthrax • Gangrene • Systemic Diseases Caused by Bites and Scratches • Vector-Transmitted Diseases

Viral Diseases of the Cardiovascular and Lymphatic Systems 668

- Burkitt's Lymphoma • Infectious Mononucleosis • Other Diseases and Epstein-Barr Virus • Cytomegalovirus Infections
- Chikungunya • Classic Viral Hemorrhagic Fevers • Emerging Viral Hemorrhagic Fevers

Protozoan Diseases of the Cardiovascular and Lymphatic Systems 674

- Chagas Disease (American Trypanosomiasis) • Toxoplasmosis
- Malaria • Leishmaniasis • Babesiosis

Helminthic Disease of the Cardiovascular and Lymphatic Systems 681

- Schistosomiasis

Disease of Unknown Etiology 683

- Kawasaki Syndrome

Study Outline • Study Questions 683

## 24 Microbial Diseases of the Respiratory System 688

Structure and Function of the Respiratory System 689

Normal Microbiota of the Respiratory System 690

MICROBIAL DISEASES OF THE UPPER RESPIRATORY SYSTEM 690

Bacterial Diseases of the Upper Respiratory System 691

- Streptococcal Pharyngitis (Strep Throat) • Scarlet Fever
- Diphtheria • Otitis Media

Viral Disease of the Upper Respiratory System 693

- The Common Cold

MICROBIAL DISEASES OF THE LOWER RESPIRATORY SYSTEM 695

Bacterial Diseases of the Lower Respiratory System 695

- Pertussis (Whooping Cough) • Tuberculosis • Bacterial Pneumonias • Melioidosis

Viral Diseases of the Lower Respiratory System 707

- Viral Pneumonia • Respiratory Syncytial Virus (RSV)
- Influenza (Flu)

Fungal Diseases of the Lower Respiratory System 711

- Histoplasmosis • Coccidioidomycosis • *Pneumocystis* Pneumonia
- Blastomycosis (North American Blastomycosis) • Other Fungi Involved in Respiratory Disease

Study Outline • Study Questions 717

## 25 Microbial Diseases of the Digestive System 721

Structure and Function of the Digestive System 722

Normal Microbiota of the Digestive System 722

Bacterial Diseases of the Mouth 724

- Dental Caries (Tooth Decay) • Periodontal Disease

Bacterial Diseases of the Lower Digestive System 727

- Staphylococcal Food Poisoning (Staphylococcal Enterotoxigenesis)
- Shigellosis (Bacillary Dysentery) • Salmonellosis (*Salmonella* Gastroenteritis) • Typhoid Fever • Cholera • Noncholera Vibrios • *Escherichia coli* Gastroenteritis • Campylobacteriosis (*Campylobacter* Gastroenteritis) • *Helicobacter* Peptic Ulcer Disease • *Yersinia* Gastroenteritis • *Clostridium perfringens* Gastroenteritis • *Clostridium difficile*-Associated Diarrhea
- *Bacillus cereus* Gastroenteritis

Viral Diseases of the Digestive System 739

- Mumps • Hepatitis • Viral Gastroenteritis

Fungal Diseases of the Digestive System 746

Protozoan Diseases of the Digestive System 747

- Giardiasis • Cryptosporidiosis • Cyclosporiasis • Amebic Dysentery (Amebiasis)

Helminthic Diseases of the Digestive System 750

- Tapeworms • Hydatid Disease • Nematodes

Study Outline • Study Questions 755

## 26 Microbial Diseases of the Urinary and Reproductive Systems 760

Structure and Function of the Urinary System 761

Structure and Function of the Reproductive Systems 761

Normal Microbiota of the Urinary and Reproductive Systems 762

DISEASES OF THE URINARY SYSTEM 763

Bacterial Diseases of the Urinary System 763

- Cystitis • Pyelonephritis • Leptospirosis

DISEASES OF THE REPRODUCTIVE SYSTEMS 766

Bacterial Diseases of the Reproductive Systems 766

Gonorrhea • Nongonococcal Urethritis (NGU) • Pelvic Inflammatory Disease (PID) • Syphilis • Lymphogranuloma Venereum (LGV) • Chancroid (Soft Chancre) • Bacterial Vaginosis

### Viral Diseases of the Reproductive Systems 776

Genital Herpes • Genital Warts • AIDS

### Fungal Disease of the Reproductive Systems 779

Candidiasis

### Protozoan Disease of the Reproductive Systems 780

Trichomoniasis

### Study Outline • Study Questions 782

## PART FIVE Environmental and Applied Microbiology

# 27 Environmental Microbiology 786

### Microbial Diversity and Habitats 787

Symbiosis

### Soil Microbiology and Biogeochemical Cycles 787

The Carbon Cycle • The Nitrogen Cycle • The Sulfur Cycle  
• Life without Sunshine • The Phosphorus Cycle • The Degradation of Synthetic Chemicals in Soil and Water

### Aquatic Microbiology and Sewage Treatment 795

Aquatic Microorganisms • The Role of Microorganisms in Water Quality • Water Treatment • Sewage (Wastewater) Treatment

### Study Outline • Study Questions 805

# 28 Applied and Industrial Microbiology 809

### Food Microbiology 810

Foods and Disease • Industrial Food Canning • Aseptic Packaging • Radiation and Industrial Food Preservation  
• High-Pressure Food Preservation • The Role of Microorganisms in Food Production

### Industrial Microbiology and Biotechnology 817

Fermentation Technology • Industrial Products  
• Alternative Energy Sources Using Microorganisms • Biofuels  
• Industrial Microbiology and the Future

### Study Outline • Study Questions 824

### Answers to Knowledge and Comprehension Study Questions AN-1

### Appendix A Metabolic Pathways AP-1

### Appendix B Exponents, Exponential Notation, Logarithms, and Generation Time AP-7

### Appendix C Methods for Taking Clinical Samples AP-8

### Appendix D Pronunciation Rules and Word Roots AP-9

### Appendix E Classification of Prokaryotes According to *Bergey's Manual* AP-12

### Glossary G-1

### Credits C-1

### Trademark Attributions T-1

### Index I-1

# Features

## EXPLORING THE MICROBIOME

- 1 How Does Your Microbiome Grow? 3
- 2 Feed Our Intestinal Bacteria, Feed Ourselves: A Tale of Two Starches 37
- 3 Obtaining a More Accurate Picture of Our Microbiota 67
- 4 Eukaryotes Are Microbiota, Too 94
- 5 Do Artificial Sweeteners (and the Intestinal Microbiota That Love Them) Promote Diabetes? 132
- 6 Circadian Rhythms and Microbiota Growth Cycles 168
- 7 Antimicrobial Soaps: Doing More Harm Than Good? 191
- 8 Horizontal Gene Transfer and the Unintended Consequences of Antibiotic Usage 230
- 9 Crime Scene Investigation and Your Microbiome 261
- 10 Techniques for Identifying Members of Your Microbiome 291
- 11 Microbiome in Space 320
- 12 The Mycobiome 335
- 13 The Human Virome 364
- 14 Connections between Birth, Microbiome, and Other Health Conditions 395
- 15 Skin Microbiota Interactions and the Making of MRSA 427
- 16 The Microbiome's Shaping of Innate Immunity 452
- 17 The Relationship between Your Immune Cells and Skin Microbiota 491
- 18 Microbiome May Enhance Response to Oral Vaccines 505
- 19 The Link between Blood Type and Composition of the Intestinal Microbiome 532
- 20 Looking to the Microbiome for the Next Great Antibiotic 585
- 21 Normal Skin Microbiota and Our Immune System: Allies in "Skin Wars" 594
- 22 Microbes Impacting the CNS 644
- 23 Is Blood Sterile? 653
- 24 Discovering the Microbiome of the Lungs 691
- 25 Sorting Out Good Neighbors from Bad in the GI Tract 723
- 26 Resident Microbes of the Urinary System 763
- 27 Resident Microbes of Earth's Most Extreme Environments 794
- 28 Using Bacteria to Stop the Spread of Zika Virus 823

## BIG PICTURE CORE TOPICS

- Metabolism 108
- Genetics 206
- Immunity 446

## BIG PICTURE DISEASES

- Vaccine-Preventable Diseases 518
- The Hygiene Hypothesis 528
- Neglected Tropical Diseases 614
- Vertical Transmission: Mother to Child 634
- Climate Change and Disease 672
- Bioterrorism 696
- Cholera After Natural Disasters 734
- STI Home Test Kits 768

## FOUNDATION FIGURES

- Figure 1.4 Disproving Spontaneous Generation 8
- Figure 2.16 The Structure of DNA 45
- Figure 3.2 Microscopes and Magnification 54
- Figure 4.6 The Structure of a Prokaryotic Cell 76
- Figure 5.11 An Overview of Respiration and Fermentation 120
- Figure 6.15 Understanding the Bacterial Growth Curve 167
- Figure 7.1 Understanding the Microbial Death Curve 181
- Figure 8.2 The Flow of Genetic Information 209
- Figure 9.1 A Typical Genetic Modification Procedure 244
- Figure 10.1 Three-Domain System 271
- Figure 12.1 Exploring Pathogenic Eukaryotes 324
- Figure 13.15 Replication of a DNA-Containing Animal Virus 379
- Figure 14.3 Koch's Postulates: Understanding Disease 399
- Figure 15.4 Mechanisms of Exotoxins and Endotoxins 431
- Figure 15.9 Microbial Mechanisms of Pathogenicity 440
- Figure 16.8 The Phases of Phagocytosis 458
- Figure 16.12 Outcomes of Complement Activation 466
- Figure 17.19 The Dual Nature of the Adaptive Immune System 495
- Figure 18.2 The Production of Monoclonal Antibodies 509
- Figure 19.17 The Progression of HIV Infection 548
- Figure 20.2 Major Action Modes of Antimicrobial Drugs 561
- Figure 20.20 Bacterial Resistance to Antibiotics 580

## LIFE CYCLE FIGURES

- Figure 11.11 Myxococcales 306
- Figure 11.15 Chlamydias 310
- Figure 12.7 The Life Cycle of *Rhizopus*, a Zygomycete 329
- Figure 12.8 The Life Cycle of *Encephalitozoon*, a Microsporidian 330
- Figure 12.9 The Life Cycle of *Talaromyces*, an Ascomycete 331
- Figure 12.10 A Generalized Life Cycle of a Basidiomycete 332
- Figure 12.13 Green Algae 339
- Figure 12.16 Oomycetes 341
- Figure 12.20 The Life Cycle of *Plasmodium vivax*, the Apicomplexan That Causes Malaria 345
- Figure 12.22 The Generalized Life Cycle of a Cellular Slime Mold 348
- Figure 12.23 The Life Cycle of a Plasmodial Slime Mold 349
- Figure 12.26 The Life Cycle of the Lung Fluke, *Paragonimus* spp. 350
- Figure 12.28 The Life Cycle of the Tapeworm, *Echinococcus* spp. 353
- Figure 23.13 The Life Cycle of the Tick Vector of Lyme Disease 665
- Figure 23.16 The Life Cycle of the Tick Vector (*Dermacentor* spp.) of Rocky Mountain Spotted Fever 667
- Figure 23.23 The Life Cycle of *Toxoplasma gondii*, the Cause of Toxoplasmosis 676
- Figure 23.27 Schistosomiasis 682
- Figure 24.17 The Life Cycle of *Coccidioides immitis*, the Cause of Coccidioidomycosis 713
- Figure 24.19 The Life Cycle of *Pneumocystis jirovecii*, the Cause of *Pneumocystis* Pneumonia 714
- Figure 25.26 The Life Cycle of *Trichinella spiralis*, the Causative Agent of Trichinellosis 754

## CLINICAL FOCUS

- Human Tuberculosis—Dallas, Texas 141
- Infection Following Cosmetic Surgery 197
- Tracking Zika Virus 218
- Norovirus—Who Is Responsible for the Outbreak? 264
- Mass Deaths of Marine Mammals Spur Veterinary Microbiology 280
- The Most Frequent Cause of Recreational Waterborne Diarrhea 351

- Influenza: Crossing the Species Barrier 367
- Healthcare-Associated Infections 417
- Serum Collection 470
- Measles: A World Health Problem 506
- A Delayed Rash 537
- Antibiotics in Animal Feed Linked to Human Disease 584
- Infections in the Gym 600
- A Neurological Disease 636
- A Sick Child 659
- Outbreak 708
- A Foodborne Infection 731
- Survival of the Fittest 771

## DISEASES IN FOCUS

- 21.1 Macular Rashes 596
- 21.2 Vesicular and Pustular Rashes 598
- 21.3 Patchy Redness and Pimple-Like Conditions 599
- 21.4 Microbial Diseases of the Eye 611
- 22.1 Meningitis and Encephalitis 627
- 22.2 Types of Arboviral Encephalitis 641
- 22.3 Microbial Diseases with Neurological Symptoms or Paralysis 646
- 23.1 Human-Reservoir Infections 657
- 23.2 Infections from Animal Reservoirs Transmitted by Direct Contact 662
- 23.3 Infections Transmitted by Vectors 663
- 23.4 Viral Hemorrhagic Fevers 675
- 23.5 Infections Transmitted by Soil and Water 681
- 24.1 Microbial Diseases of the Upper Respiratory System 694
- 24.2 Common Bacterial Pneumonias 704
- 24.3 Microbial Diseases of the Lower Respiratory System 716
- 25.1 Bacterial Diseases of the Mouth 727
- 25.2 Bacterial Diseases of the Lower Digestive System 740
- 25.3 Characteristics of Viral Hepatitis 743
- 25.4 Viral Diseases of the Digestive System 747
- 25.5 Fungal, Protozoan, and Helminthic Diseases of the Lower Digestive System 748
- 26.1 Bacterial Diseases of the Urinary System 764
- 26.2 Characteristics of the Most Common Types of Vaginitis and Vaginosis 779
- 26.3 Microbial Diseases of the Reproductive Systems 781

# ASM Recommended Curriculum Guidelines for Undergraduate Microbiology

The American Society for Microbiology (ASM) endorses a concept-based curriculum for introductory microbiology, emphasizing skills and concepts that remain important long after students exit the course. The ASM *Curriculum Guidelines for Undergraduate Microbiology Education* provide a framework for key microbiological topics and agree with scientific literacy reports from the American Association for the Advancement of Science and Howard Hughes Medical Institute. This textbook references part one of curriculum guidelines throughout chapters. When a discussion touches on one of the concepts, readers will see the ASM icon, along with a summary of the relevant statement.



## ASM Guideline Concepts and Statements

### Evolution

- Cells, organelles (e.g., mitochondria and chloroplasts), and all major metabolic pathways evolved from early prokaryotic cells.
- Mutations and horizontal gene transfer, with the immense variety of microenvironments, have selected for a huge diversity of microorganisms.
- Human impact on the environment influences the evolution of microorganisms (e.g., emerging diseases and the selection of antibiotic resistance).
- The traditional concept of species is not readily applicable to microbes due to asexual reproduction and the frequent occurrence of horizontal gene transfer.
- The evolutionary relatedness of organisms is best reflected in phylogenetic trees.

### Cell Structure and Function

- The structure and function of microorganisms have been revealed by the use of microscopy (including brightfield, phase contrast, fluorescent, and electron).
- Bacteria have unique cell structures that can be targets for antibiotics, immunity, and phage infection.
- Bacteria and Archaea have specialized structures (e.g. flagella, endospores, and pili) that often confer critical capabilities.
- 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.
- The replication cycles of viruses (lytic and lysogenic) differ among viruses and are determined by their unique structures and genomes.

### Metabolic Pathways

- Bacteria and Archaea exhibit extensive, and often unique, metabolic diversity (e.g., nitrogen fixation, methane production, anoxygenic photosynthesis).
- The interactions of microorganisms among themselves and with their environment are determined by their metabolic abilities (e.g., quorum sensing, oxygen consumption, nitrogen transformations).
- The survival and growth of any microorganism in a given environment depend on its metabolic characteristics.
- The growth of microorganisms can be controlled by physical, chemical, mechanical, or biological means.

### Information Flow and Genetics

- Genetic variations can impact microbial functions (e.g., in biofilm formation, pathogenicity, and drug resistance).
- Although the central dogma is universal in all cells, the processes of replication, transcription, and translation differ in Bacteria, Archaea, and Eukaryotes.
- The regulation of gene expression is influenced by external and internal molecular cues and/or signals.
- The synthesis of viral genetic material and proteins is dependent on host cells.
- Cell genomes can be manipulated to alter cell function.

### Microbial Systems

- Microorganisms are ubiquitous and live in diverse and dynamic ecosystems.
- Most bacteria in nature live in biofilm communities.
- Microorganisms and their environment interact with and modify each other.
- Microorganisms, cellular and viral, can interact with both human and nonhuman hosts in beneficial, neutral, or detrimental ways.

### Impact of Microorganisms

- 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).
- Microorganisms provide essential models that give us fundamental knowledge about life processes.
- Humans utilize and harness microorganisms and their products.
- Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored.

# The Microbial World and You 1

The overall theme of this textbook is the relationship between microbes—very small organisms that usually require a microscope to be seen—and our lives. We've all heard of epidemics of infectious diseases such as plague or smallpox that wiped out populations. However, there are many positive examples of human-microbe interactions. For example, we use microbial fermentation to ensure safe food supplies, and the human microbiome, a group of microbes that lives in and on our bodies, helps keep us healthy. We begin this chapter by discussing how organisms are named and classified and then follow with a short history of microbiology. Next, we discuss the incredible diversity of microorganisms and their ecological importance, noting how they recycle chemical elements such as carbon and nitrogen among the soil, organisms, and the atmosphere.



ASM: Microorganisms provide essential models that give us fundamental knowledge about life processes.

We also examine how microbes are used to treat sewage, clean pollutants, control pests, and produce foods, chemicals, and drugs. Finally, we will discuss microbes as the cause of diseases such as Zika virus disease, avian (bird) flu, Ebola virus disease, and diarrhea, and we examine the growing public health problem of antibiotic-resistant bacteria.

Shown in the photograph are *Staphylococcus aureus* (STAF-i-lō-kok'kus OR-ē-us) bacteria on human nasal epithelial cells. These bacteria generally live harmlessly on skin or inside the nose.

Misuse of antibiotics, however, allows the survival of bacteria with antibiotic-resistance genes, such as methicillin-resistant *S. aureus* (MRSA). As illustrated in the Clinical Case, an infection caused by these bacteria is resistant to antibiotic treatment.

◀ *Staphylococcus aureus* bacteria on skin cell culture.

## In the Clinic

As the nurse practitioner in a rural hospital, you are reviewing a microscope slide of a skin scraping from a 12-year-old girl. The slide shows branched, intertwined nucleated hyphae. The girl has dry, scaly, itchy patches on her arms. **What is causing her skin problem?**

Hint: Read about types of microorganisms (pages 4–6).



Play In the Clinic Video @  
MasteringMicrobiology



## Microbes in Our Lives

### LEARNING OBJECTIVES

**1-1** List several ways in which microbes affect our lives.

**1-2** Define *microbiome*, *normal microbiota*, and *transient microbiota*.

For many people, the words *germ* and *microbe* bring to mind a group of tiny creatures that do not quite fit into any of the categories in that old question, “Is it animal, vegetable, or mineral?” *Germ* actually comes from the Latin word *germen*, meaning to spout from, or germinate. Think of wheat germ, the plant embryo from which the plant grows. It was first used in relation to microbes in the nineteenth century to explain the rapidly growing cells that caused disease. **Microbes**, also called **microorganisms**, are minute living things that individually are usually too small to be seen with the unaided eye. The group includes bacteria, fungi (yeasts and molds), protozoa, and microscopic algae. It also includes viruses, those noncellular entities sometimes regarded as straddling the border between life and nonlife (Chapters 11, 12, and 13, respectively).

We tend to associate these small organisms only with infections and inconveniences such as spoiled food. However, the majority of microorganisms actually help maintain the balance of life in our environment. Marine and freshwater microorganisms form the basis of the food chain in oceans, lakes, and rivers. Soil microbes break down wastes and incorporate nitrogen gas from the air into organic compounds, thereby recycling chemical elements among soil, water, living organisms, and air. Certain microbes play important roles in *photosynthesis*, a food- and oxygen-generating process that is critical to life on Earth.

Microorganisms also have many commercial applications. They are used in the synthesis of such chemical products as vitamins, organic acids, enzymes, alcohols, and many drugs. For example, microbes are used to produce acetone and butanol, and the vitamins B<sub>2</sub> (riboflavin) and B<sub>12</sub> (cobalamin) are made biochemically. The process by which microbes produce acetone and butanol was discovered in 1914 by Chaim Weizmann, a Russian-born chemist working in England. With the outbreak of World War I in August of that year, the production of acetone became very important for making cordite (a smokeless form of gunpowder used in munitions). Weizmann’s discovery played a significant role in determining the outcome of the war.

The food industry also uses microbes in producing, for example, vinegar, sauerkraut, pickles, soy sauce, cheese, yogurt, bread, and alcoholic beverages. In addition, enzymes from microbes can now be manipulated to cause the microbes to produce substances they normally don’t synthesize, including cellulose, human insulin, and proteins for vaccines.

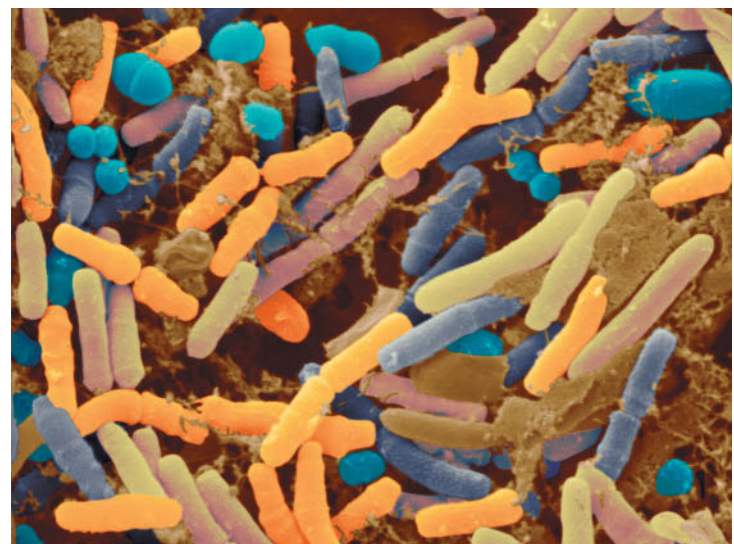
### The Microbiome

An adult human is composed of about 30 trillion body cells and harbors another 40 trillion bacterial cells. Microbes that live stably in and on the human body are called the human

**microbiome**, or **microbiota**. Humans and many other animals depend on these microbes to maintain good health. Bacteria in our intestines, including *E. coli*, aid digestion (see Exploring the Microbiome on page 3) and even synthesize some vitamins that our bodies require, including B vitamins for metabolism and vitamin K for blood clotting. They also prevent growth of **pathogenic** (disease-causing) species that might otherwise take up residence, and they seem to have a role in training our immune system to know which foreign invaders to attack and which to leave alone. (See Chapter 14 for more details on relationships between normal microbiota and the host.)

Even before birth, our bodies begin to be populated with bacteria. As newborns, we acquire viruses, fungi, and bacteria (**Figure 1.1**). For example, *E. coli* and other bacteria acquired from foods take residence in the large intestine. Many factors influence where and whether a microbe can indefinitely colonize the body as benign **normal microbiota** or be only a fleeting member of its community (known as **transient microbiota**). Microbes can colonize only those body sites that can supply the appropriate nutrients. Temperature, pH, and the presence or absence of chemical compounds are some factors that influence what types of microbes can flourish.

To determine the makeup of typical microbiota of various areas of the body, and to understand the relationship between changes in the microbiome and human diseases, is the goal of the **Human Microbiome Project**, which began in 2007. Likewise, the **National Microbiome Initiative (NMI)** launched in 2016 to expand our understanding of the role microbes play in different ecosystems, including soil, plants, aquatic environments, and the human body. Throughout the book, look for



SEM | 3 μm

**Figure 1.1** Several types of bacteria found as part of the normal microbiota in an infant’s intestine.

**Q** How do we benefit from the production of vitamin K by microbes?

The specific traits of microbes that reside in human intestines can vary greatly—even within the same microbial species. Take *Bacteroides*, a bacterium commonly found in gastrointestinal tracts of humans worldwide. The strain residing in Japanese people has specialized enzymes that break down nori, the red algae used as the wrap component of sushi. These enzymes are absent from *Bacteroides* found in the gastrointestinal tracts of North Americans.

How did the Japanese *Bacteroides* acquire the ability to digest algae? It's thought the skill hails from *Zobellia galactanivorans*, a marine bacterium that lives on this alga. Not surprisingly, *Zobellia* readily breaks down the alga's main carbohydrate with enzymes. Since people living in Japan consumed algae regularly, *Zobellia* routinely met up with *Bacteroides* that lived in the human intestine. Bacteria

can swap genes with other species—a process called *horizontal gene transfer*—and at some point, *Zobellia* must have given *Bacteroides* the genes to produce algae-digesting enzymes. (For more on horizontal gene transfer, see Chapter 8).

In an island nation where algae are an important diet component, the ability to extract more nutrition from algal carbohydrates would give an intestinal microbe a competitive advantage over others that couldn't use it as a food source. Over time, this *Bacteroides* strain became the dominant one found within the gastrointestinal tracts of people living in Japan.

You may be wondering whether North American sushi eaters can expect their own *Bacteroides* to shift to the algae-eating variety, too. Researchers say this is unlikely. Traditional Japanese food included raw algae, which allowed for living *Zobellia* to reach the large intestine. By contrast, the

algae used in foods today is usually roasted or dried; these processes kill any bacteria that may be present on the surface.



*Porphyra*, an alga commonly used in sushi.

stories related to the human microbiome, highlighted in the Exploring the Microbiome feature boxes.

Our realization that some microbes are not only harmless to humans, but also are actually essential, represents a large shift from the traditional view that the only good microbe was a dead one. In fact, only a minority of microorganisms are pathogenic to humans. Although anyone planning to enter a health care profession needs to know how to prevent the transmission and spread of pathogenic microbes, it's also important to know that pathogens are just one aspect of our full relationship with microbes.

Today we understand that microorganisms are found almost everywhere. Yet not long ago, before the invention of the microscope, microbes were unknown to scientists. Next we'll look at the major groups of microbes and how they are named and classified. After that, we'll examine a few historic milestones in microbiology that have changed our lives.

#### CHECK YOUR UNDERSTANDING

- ✓ **1-1\*** Describe some of the destructive and beneficial actions of microbes.
- ✓ **1-2** What percentage of all the cells in the human body are bacterial cells?

\* The numbers preceding Check Your Understanding questions refer to the corresponding Learning Objectives.

#### CLINICAL CASE A Simple Spider Bite?

Andrea is a normally healthy 22-year-old college student who lives at home with her mother and younger sister, a high school gymnast. She is trying to work on a paper for her psychology class but is having a hard time because a red, swollen sore on her right wrist is making typing difficult. “Why won't this spider bite heal?” she wonders. “It's been there for days!” She makes an appointment with her doctor so she can show him the painful lesion. Although Andrea does not have a fever, she does have an elevated white blood cell count that indicates a bacterial infection. Andrea's doctor suspects that this isn't a spider bite at all, but a staph infection. He prescribes a  $\beta$ -lactam antibiotic, cephalosporin. Learn more about the development of Andrea's illness on the following pages.

**What is staph? Read on to find out.**

3

16

18

19



## Naming and Classifying Microorganisms

### LEARNING OBJECTIVES

- 1-3** Recognize the system of scientific nomenclature that uses two names: a genus and a specific epithet.
- 1-4** Differentiate the major characteristics of each group of microorganisms.
- 1-5** List the three domains.

### Nomenclature

The system of nomenclature (naming) for organisms in use today was established in 1735 by Carolus Linnaeus. Scientific names are latinized because Latin was the language traditionally used by scholars. Scientific nomenclature assigns each organism two names—the **genus** (plural: **genera**) is the first name and is always capitalized; the **specific epithet** (**species name**) follows and is not capitalized. The organism is referred to by both the genus and the specific epithet, and both names are underlined or italicized. By custom, after a scientific name has been mentioned once, it can be abbreviated with the initial of the genus followed by the specific epithet.

Scientific names can, among other things, describe an organism, honor a researcher, or identify the habitat of a species. For example, consider *Staphylococcus aureus*, a bacterium commonly found on human skin. *Staphylo-* describes the clustered arrangement of the cells; *-coccus* indicates that they are shaped like spheres. The specific epithet, *aureus*, is Latin for golden, the color of many colonies of this bacterium. The genus of the bacterium *Escherichia coli* (esh'er-ik-ē-ah KŌ-lī, or KŌ-lē) is named for a physician, Theodor Escherich, whereas its specific epithet,

*coli*, reminds us that *E. coli* live in the colon, or large intestine. Table 1.1 contains more examples.

### CHECK YOUR UNDERSTANDING

- ✓ **1-3** Distinguish a genus from a specific epithet.

### Types of Microorganisms

In health care, it is very important to know the different types of microorganisms in order to treat infections. For example, antibiotics can be used to treat bacterial infections but have no effect on viruses or other microbes. Here is an overview of the main types of microorganisms. (The classification and identification of microorganisms are discussed in Chapter 10.)

#### Bacteria

**Bacteria** (singular: **bacterium**) are relatively simple, single-celled (unicellular) organisms. Because their genetic material is not enclosed in a special nuclear membrane, bacterial cells are called **prokaryotes** (prō-KAR-e-ōts), from Greek words meaning prenucleus. Prokaryotes include both bacteria and archaea.

Bacterial cells generally appear in one of several shapes. *Bacillus* (bah-SIL-lus) (rodlike), illustrated in Figure 1.2a, *coccus* (KOK-kus) (spherical or ovoid), and *spiral* (corkscrew or curved) are among the most common shapes, but some bacteria are star-shaped or square (see Figures 4.1 through 4.5, pages 74–75). Individual bacteria may form pairs, chains, clusters, or other groupings; such formations are usually characteristic of a particular genus or species of bacteria.

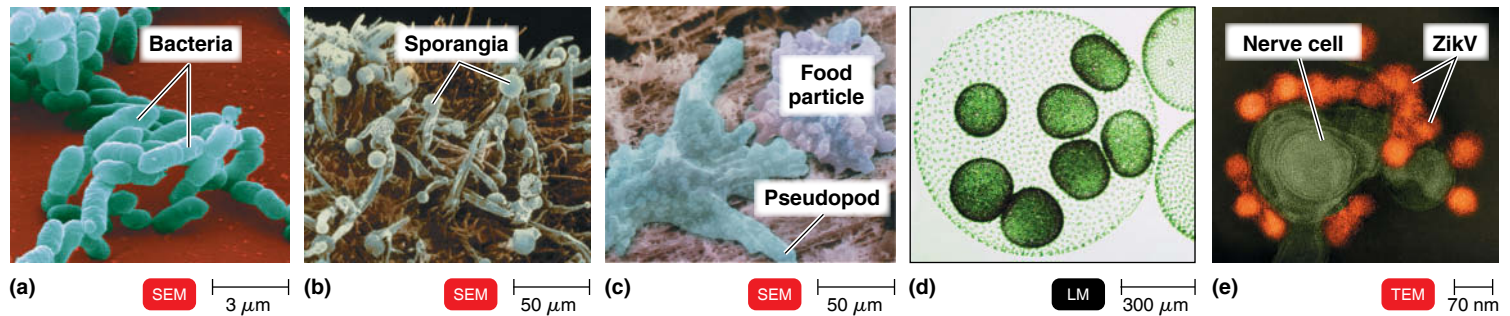
Bacteria are enclosed in cell walls that are largely composed of a carbohydrate and protein complex called *peptidoglycan*.

**TABLE 1.1** Making Scientific Names Familiar

Use the word roots guide to find out what the name means. The name will not seem so strange if you translate it. When you encounter a new name, practice saying it out loud (guidelines for pronunciation are given in Appendix D). The exact pronunciation is not as important as the familiarity you will gain.

Following are some examples of microbial names you may encounter in the popular press as well as in the lab.

	Pronunciation	Source of Genus Name	Source of Specific Epithet
<i>Salmonella enterica</i> (bacterium)	sal'mō-NEL-lah en-TER-i-kah	Honors public health microbiologist Daniel Salmon	Found in the intestines ( <i>entero-</i> )
<i>Streptococcus pyogenes</i> (bacterium)	strep'tō-KOK-kus pī-AH-jen-ēz	Appearance of cells in chains ( <i>strepto-</i> )	Forms pus ( <i>pyo-</i> )
<i>Saccharomyces cerevisiae</i> (yeast)	sak'kar-ō-MĪ-sēz se-ri-VIS-ē-ī	Fungus ( <i>-myces</i> ) that uses sugar ( <i>saccharo-</i> )	Makes beer ( <i>cerevisia</i> )
<i>Penicillium chrysogenum</i> (fungus)	pen'i-SIL-lē-um krī-SO-jen-um	Tuftlike or paintbrush ( <i>penicill-</i> ) appearance microscopically	Produces a yellow ( <i>chryso-</i> ) pigment
<i>Trypanosoma cruzi</i> (protozoan)	tri'pa-nō-SŌ-mah KROOZ-ē	Corkscrew- ( <i>trypano-</i> , borer; <i>soma-</i> , body)	Honors epidemiologist Oswaldo Cruz



**Figure 1.2** Types of microorganisms.

(a) The rod-shaped bacterium *Haemophilus influenzae*, one of the bacterial causes of pneumonia. (b) *Mucor*, a common bread mold, is a type of fungus. When released from sporangia, spores that land on a favorable surface germinate into a network of hyphae

(filaments) that absorb nutrients. (c) An amoeba, a type of protozoan, approaching a food particle. (d) The pond alga *Volvox*. (e) Zika virus (ZikV). NOTE: Throughout the book, a red icon under a micrograph indicates that the micrograph has been artificially colored. SEM (scanning

electron microscope) and LM (light microscope) are discussed in detail in Chapter 3.

**Q** How are bacteria, archaea, fungi, protozoa, algae, and viruses distinguished on the basis of structure?

(By contrast, cellulose is the main substance of plant and algal cell walls.) Bacteria generally reproduce by dividing into two equal cells; this process is called *binary fission*. For nutrition, most bacteria use organic chemicals, which in nature can be derived from either dead or living organisms. Some bacteria can manufacture their own food by photosynthesis, and some can derive nutrition from inorganic substances. Many bacteria can “swim” by using moving appendages called *flagella*. (For a complete discussion of bacteria, see Chapter 11.)

### Archaea

Like bacteria, **archaea** (ar-KĒ-ah) consist of prokaryotic cells, but if they have cell walls, the walls lack peptidoglycan. Archaea, often found in extreme environments, are divided into three main groups. The *methanogens* produce methane as a waste product from respiration. The *extreme halophiles* (*halo* = salt; *philic* = loving) live in extremely salty environments such as the Great Salt Lake and the Dead Sea. The *extreme thermophiles* (*therm* = heat) live in hot sulfurous water, such as hot springs at Yellowstone National Park. Archaea are not known to cause disease in humans.

### Fungi

**Fungi** (singular: **fungus**) are **eukaryotes** (ū-KAR-ē-ōts), organisms whose cells have a distinct nucleus containing the cell’s genetic material (DNA), surrounded by a special envelope called the *nuclear membrane*. Organisms in the Kingdom Fungi may be unicellular or multicellular (see Chapter 12, page 324). Large multicellular fungi, such as mushrooms, may look somewhat like plants, but unlike most plants, fungi cannot carry out photosynthesis. True fungi have cell walls composed primarily of a substance called *chitin*. The unicellular forms of fungi, *yeasts*, are oval microorganisms that are larger than bacteria. The most typical fungi are *molds* (Figure 1.2b). Molds form

visible masses called *mycelia*, which are composed of long filaments (*hyphae*) that branch and intertwine. The cottony growths sometimes found on bread and fruit are mold mycelia. Fungi can reproduce sexually or asexually. They obtain nourishment by absorbing organic material from their environment—whether soil, seawater, freshwater, or an animal or plant host. Organisms called *slime molds* are actually amoeba-like protozoa (see Chapter 12).

### Protozoa

**Protozoa** (singular: **protozoan**) are unicellular eukaryotic microbes (see Chapter 12, page 341). Protozoa move by pseudopods, flagella, or cilia. Amoebae (Figure 1.2c) move by using extensions of their cytoplasm called *pseudopods* (false feet). Other protozoa have long *flagella* or numerous shorter appendages for locomotion called *cilia*. Protozoa have a variety of shapes and live either as free entities or as *parasites* (organisms that derive nutrients from living hosts) that absorb or ingest organic compounds from their environment. Some protozoa, such as *Euglena* (ū-GLĒ-nah), are photosynthetic. They use light as a source of energy and carbon dioxide as their chief source of carbon to produce sugars. Protozoa can reproduce sexually or asexually.

### Algae

**Algae** (singular: **alga**) are photosynthetic eukaryotes with a wide variety of shapes and both sexual and asexual reproductive forms (Figure 1.2d). The algae of interest to microbiologists are usually unicellular (see Chapter 12, page 337). The cell walls of many algae are composed of a carbohydrate called *cellulose*. Algae are abundant in freshwater and saltwater, in soil, and in association with plants. As photosynthesizers, algae need light, water, and carbon dioxide for food production and growth, but they do not generally require organic compounds

from the environment. As a result of photosynthesis, algae produce oxygen and carbohydrates that are then utilized by other organisms, including animals. Thus, they play an important role in the balance of nature.

### Viruses

**Viruses** (Figure 1.2e) are very different from the other microbial groups mentioned here. They are so small that most can be seen only with an electron microscope, and they are acellular (that is, they are not cells). Structurally very simple, a virus particle contains a core made of only one type of nucleic acid, either DNA or RNA. This core is surrounded by a protein coat, which is sometimes encased by a lipid membrane called an *envelope*. All living cells have RNA and DNA, can carry out chemical reactions, and can reproduce as self-sufficient units. Viruses can reproduce only by using the cellular machinery of other organisms. Thus, on the one hand, viruses are considered to be living only when they multiply within host cells they infect. In this sense, viruses are parasites of other forms of life. On the other hand, viruses are not considered to be living because they are inert outside living hosts. (Viruses will be discussed in detail in Chapter 13.)

### Multicellular Animal Parasites

Although multicellular animal parasites are not strictly microorganisms, they are of medical importance and therefore will be discussed in this text. Animal parasites are eukaryotes. The two major groups of parasitic worms are the flatworms and the roundworms, collectively called **helminths** (see Chapter 12, page 347). During some stages of their life cycle, helminths are microscopic in size. Laboratory identification of these organisms includes many of the same techniques used for identifying microbes.

#### CHECK YOUR UNDERSTANDING

- 1-4 Which groups of microbes are prokaryotes? Which are eukaryotes?

## Classification of Microorganisms

Before the existence of microbes was known, all organisms were grouped into either the animal kingdom or the plant kingdom. When microscopic organisms with characteristics of animals and plants were discovered late in the seventeenth century, a new system of classification was needed. Still, biologists couldn't agree on the criteria for classifying these new organisms until the late 1970s.

In 1978, Carl Woese devised a system of classification based on the cellular organization of organisms. It groups all organisms in three domains as follows:

1. Bacteria (cell walls contain a protein-carbohydrate complex called peptidoglycan)
2. Archaea (cell walls, if present, lack peptidoglycan)
3. Eukarya, which includes the following:
  - Protists (slime molds, protozoa, and algae)
  - Fungi (unicellular yeasts, multicellular molds, and mushrooms)
  - Plants (mosses, ferns, conifers, and flowering plants)
  - Animals (sponges, worms, insects, and vertebrates)

Classification will be discussed in more detail in Chapters 10 through 12.

#### CHECK YOUR UNDERSTANDING

- 1-5 What are the three domains?

## A Brief History of Microbiology

### LEARNING OBJECTIVES

- 1-6 Explain the importance of observations made by Hooke and van Leeuwenhoek.
- 1-7 Compare spontaneous generation and biogenesis.
- 1-8 Identify the contributions to microbiology made by Needham, Spallanzani, Virchow, and Pasteur.
- 1-9 Explain how Pasteur's work influenced Lister and Koch.
- 1-10 Identify the importance of Koch's postulates.
- 1-11 Identify the importance of Jenner's work.
- 1-12 Identify the contributions to microbiology made by Ehrlich and Fleming.
- 1-13 Define *bacteriology*, *mycology*, *parasitology*, *immunology*, and *virology*.
- 1-14 Explain the importance of microbial genetics, molecular biology, and genomics.

Bacterial ancestors were the first living cells to appear on Earth. For most of human history, people knew little about the true causes, transmission, and effective treatment of disease. Let's look now at some key developments in microbiology that have spurred the field to its current technological state.

### The First Observations

In 1665, after observing a thin slice of cork through a crude microscope, Englishman Robert Hooke reported that life's smallest structural units were "little boxes," or "cells." Using his improved microscope, Hooke later saw individual cells. Hooke's discovery marked the beginning of the **cell theory**—the theory that *all living things are composed of cells*.

Though Hooke's microscope was capable of showing large cells, it lacked the resolution that would have allowed him to see microbes clearly. Dutch merchant and amateur scientist Anton van Leeuwenhoek was probably the first to observe live microorganisms through the magnifying lenses of the more than

400 microscopes he constructed. Between 1673 and 1723, he wrote about the “animalcules” he saw through his simple, single-lens microscopes. Van Leeuwenhoek made detailed drawings of organisms he found in rainwater, feces, and material scraped from teeth. These drawings have since been identified as representations of bacteria and protozoa (Figure 1.3).

### CHECK YOUR UNDERSTANDING

✓ 1-6 What is the cell theory?

## The Debate over Spontaneous Generation

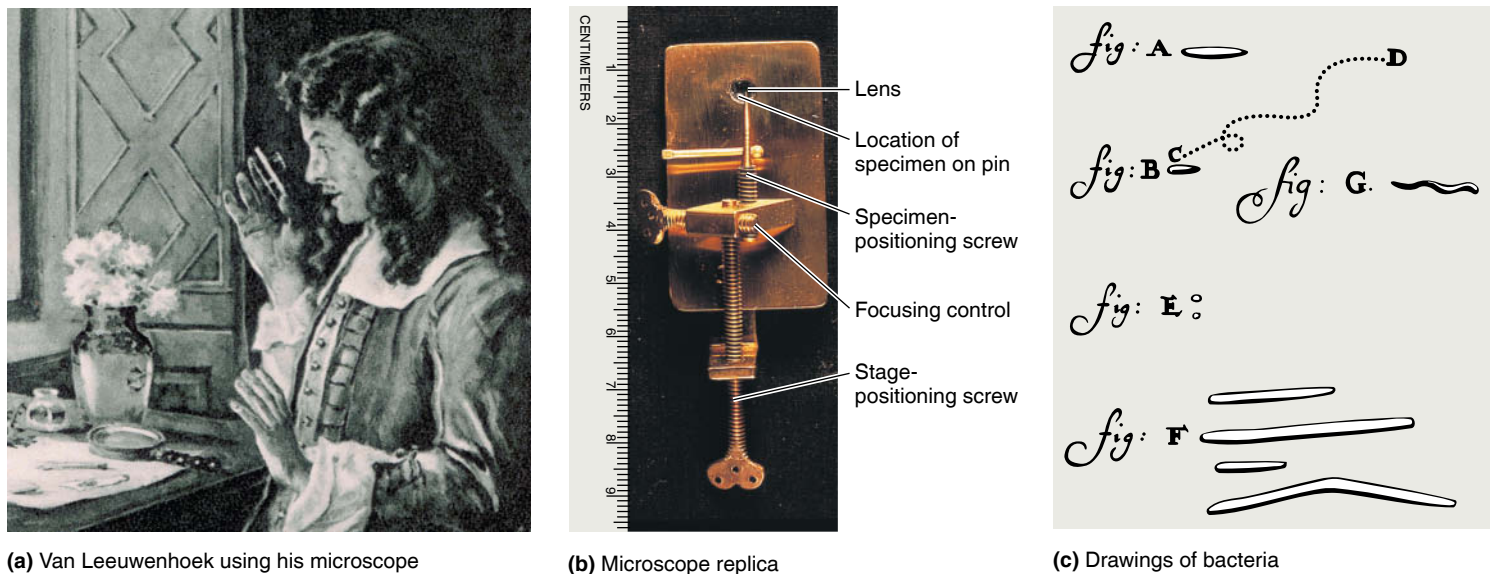
After van Leeuwenhoek discovered the previously “invisible” world of microorganisms, the scientific community became interested in the origins of these tiny living things. Until the second half of the nineteenth century, many scientists and philosophers believed that some forms of life could arise spontaneously from nonliving matter; they called this hypothetical process **spontaneous generation**. Not much more than 100 years ago, people commonly believed that toads, snakes, and mice could be born of moist soil; that flies could emerge from manure; and that maggots (which we now know are the larvae of flies) could arise from decaying corpses.

Physician Francesco Redi set out in 1668 to demonstrate that maggots did not arise spontaneously. Redi filled two jars with decaying meat. The first was left unsealed, allowing

flies to lay eggs on the meat, which developed into larvae. The second jar was sealed, and because the flies could not get inside, no maggots appeared. Still, Redi’s antagonists were not convinced; they claimed that fresh air was needed for spontaneous generation. So Redi set up a second experiment, in which he covered a jar with a fine net instead of sealing it. No larvae appeared in the gauze-covered jar, even though air was present.

Redi’s results were a serious blow to the long-held belief that large forms of life could arise from nonlife. However, many scientists still believed that small organisms, such as van Leeuwenhoek’s “animalcules,” were simple enough to generate from nonliving materials.

The case for spontaneous generation of microorganisms seemed to be strengthened in 1745, when John Needham found that even after he heated chicken broth and corn broth before pouring them into covered flasks, the cooled solutions were soon teeming with microorganisms. Needham claimed that microbes developed spontaneously from the fluids. Twenty years later, Lazzaro Spallanzani suggested that microorganisms from the air probably entered Needham’s solutions after they were boiled. Spallanzani showed that nutrient fluids heated *after* being sealed in a flask did not develop microbial growth. Needham responded by claiming the “vital force” necessary for spontaneous generation had been destroyed by the heat and was kept out of the flasks by the seals.



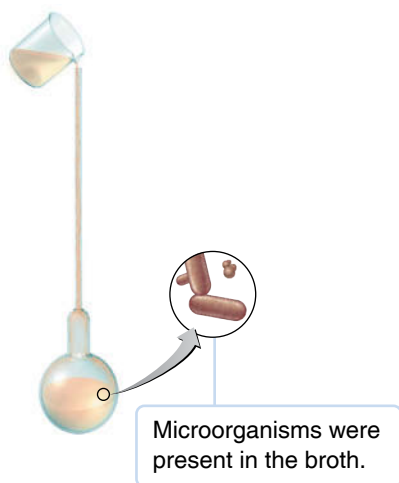
**Figure 1.3 Anton van Leeuwenhoek’s microscopic observations.** (a) By holding his brass microscope toward a source of light, van Leeuwenhoek was able to observe living organisms too small to be seen with the unaided eye. (b) The specimen was placed on the tip of the adjustable point and viewed from the other side through the tiny, nearly spherical lens. The highest magnification possible with his microscopes was about 300 $\times$  (times). (c) Some of van Leeuwenhoek’s drawings of bacteria, made in 1683. The letters represent various shapes of bacteria. C–D represents a path of motion he observed.

**Q** Why was van Leeuwenhoek’s discovery so important?

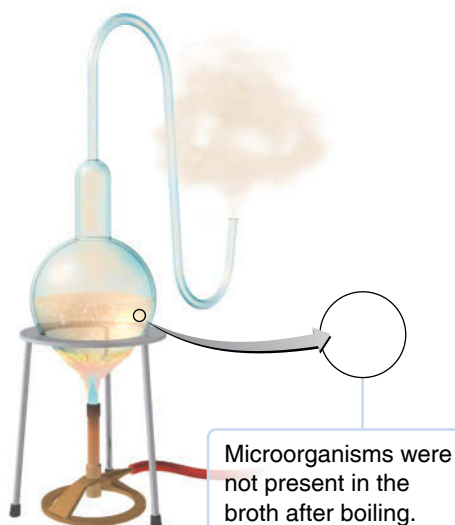
# Disproving Spontaneous Generation

According to the hypothesis of spontaneous generation, life can arise spontaneously from nonliving matter, such as dead corpses and soil. Pasteur's experiment, described below, demonstrated that microbes are present in nonliving matter—air, liquids, and solids.

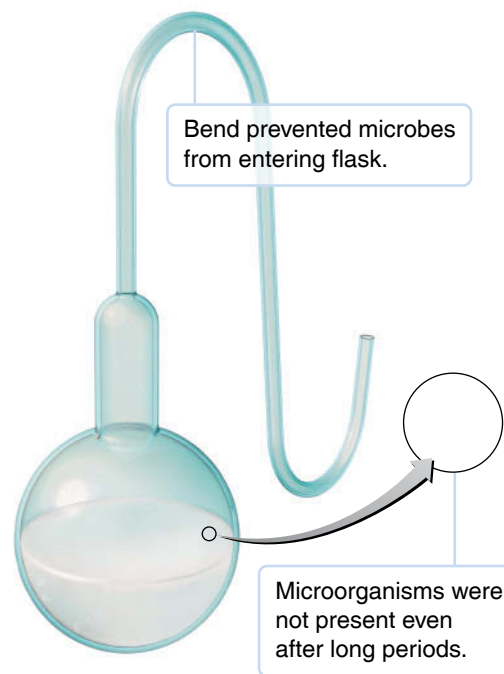
- 1 Pasteur first poured beef broth into a long-necked flask.



- 2 Next he heated the neck of the flask and bent it into an S-shape; then he boiled the broth for several minutes.



- 3 Microorganisms did not appear in the cooled solution, even after long periods.



## KEY CONCEPTS

- Pasteur demonstrated that microbes are responsible for food spoilage, leading researchers to the connection between microbes and disease.
- His experiments and observations provided the basis of aseptic techniques, which are used to prevent microbial contamination, as shown in the photo at right.



Some of these original vessels are still on display at the Pasteur Institute in Paris. They have been sealed but show no sign of contamination more than 100 years later.

Spallanzani's observations were also criticized on the grounds that there was not enough oxygen in the sealed flasks to support microbial life.

## The Theory of Biogenesis

In 1858 Rudolf Virchow challenged the case for spontaneous generation with the concept of **biogenesis**, hypothesizing that living cells arise only from preexisting living cells. Because he could offer no scientific proof, arguments about spontaneous generation continued until 1861, when the issue was finally resolved by the French scientist Louis Pasteur.

Pasteur demonstrated that microorganisms are present in the air and can contaminate sterile solutions, but that air itself does not create microbes. He filled several short-necked

flasks with beef broth and then boiled their contents. Some were then left open and allowed to cool. In a few days, these flasks were found to be contaminated with microbes. The other flasks, sealed after boiling, were free of microorganisms. From these results, Pasteur reasoned that microbes in the air were the agents responsible for contaminating nonliving matter.

Pasteur next placed broth in open-ended, long-necked flasks and bent the necks into S-shaped curves (**Figure 1.4**). The contents of these flasks were then boiled and cooled. The broth in the flasks did not decay and showed no signs of life, even after months. Pasteur's unique design allowed air to pass into the flask, but the curved neck trapped any airborne microorganisms that might contaminate the broth. (Some of these original vessels are still on display at the Pasteur Institute in

Paris. They have been sealed but, like the flask in Figure 1.4, show no sign of contamination more than 100 years later.)

Pasteur showed that microorganisms can be present in nonliving matter—on solids, in liquids, and in the air. Furthermore, he demonstrated conclusively that microbial life can be destroyed by heat and that methods can be devised to block the access of airborne microorganisms to nutrient environments. These discoveries form the basis of **aseptic techniques**, procedures that prevent contamination by unwanted microorganisms, which are now the standard practice in laboratory and many medical procedures. Modern aseptic techniques are among the first and most important concepts that a beginning microbiologist learns.

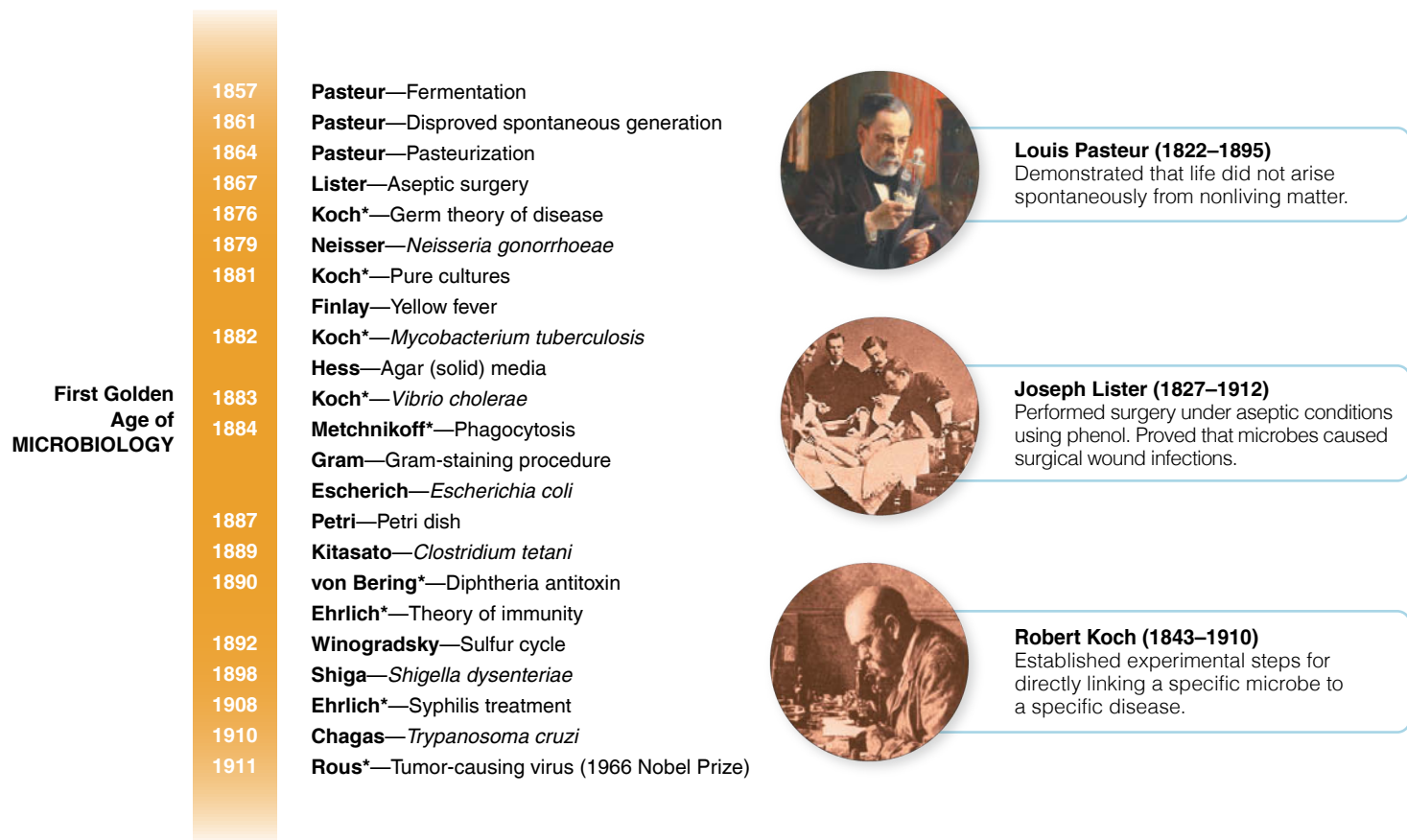
Pasteur's work provided evidence that microorganisms cannot originate from mystical forces present in nonliving materials. Rather, any appearance of "spontaneous" life in nonliving solutions can be attributed to microorganisms that were already present in the air or in the fluids themselves. Scientists now believe that a form of spontaneous generation probably did occur on the primitive Earth when life first began, but they agree that this does not happen under today's environmental conditions.

### CHECK YOUR UNDERSTANDING

- ✓ 1-7 What evidence supported spontaneous generation?
- ✓ 1-8 How was spontaneous generation disproved?

## The First Golden Age of Microbiology

The period from 1857 to 1914 has been appropriately named the First Golden Age of Microbiology. Rapid advances, spearheaded mainly by Pasteur and Robert Koch, led to the establishment of microbiology. Discoveries included both the agents of many diseases and the role of immunity in preventing and curing disease. During this productive period, microbiologists studied the chemical activities of microorganisms, improved the techniques for performing microscopy and culturing microorganisms, and developed vaccines and surgical techniques. Some of the major events that occurred during the First Golden Age of Microbiology are listed in **Figure 1.5**.



**Figure 1.5** Milestones in the First Golden Age of Microbiology. An asterisk (\*) indicates a Nobel laureate.

**Q** Why do you think the First Golden Age of Microbiology occurred when it did?