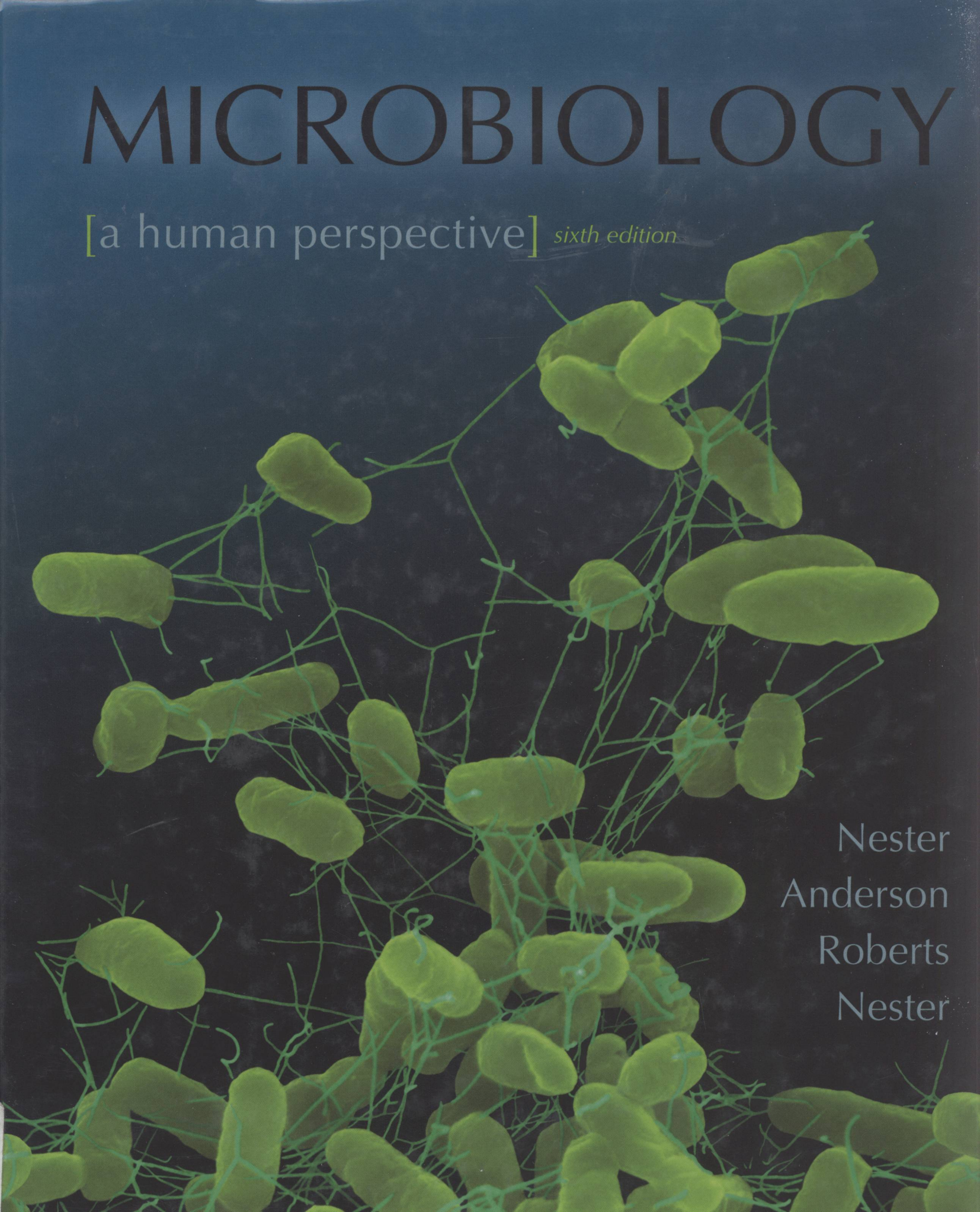


MICROBIOLOGY

[a human perspective] *sixth edition*



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sixth edition

MICROBIOLOGY

A HUMAN PERSPECTIVE

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MICROBIOLOGY: A HUMAN PERSPECTIVE, SIXTH EDITION

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MICROBIOLOGY

A HUMAN PERSPECTIVE

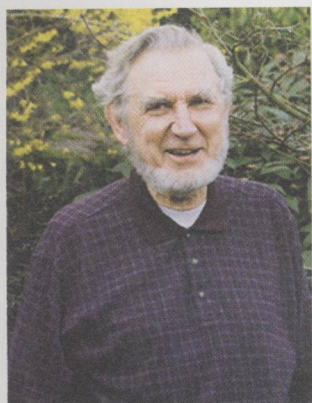
We dedicate this book to our students;
we hope it helps to enrich their lives and to make them
better informed citizens,

to our families
whose patience and endurance
made completion of this project a reality,

to Anne Nongthanat Panarak Roberts
in recognition of her invaluable help,
patience, and understanding,

to our colleagues
for continuing encouragement
and advice.

ABOUT THE AUTHORS



Eugene Nester

Eugene (Gene) Nester performed his undergraduate work at Cornell University and received his Ph.D. in Microbiology from Case Western University. He then pursued postdoctoral work in the Department of Genetics at Stanford University with Joshua Lederberg. Since 1962, Gene has been a faculty member in the Department of Microbiology at the University of Washington. Gene's research has focused on gene transfer systems in bacteria. His laboratory

demonstrated that *Agrobacterium* transfers DNA into plant cells, the basis for the disease crown gall. He continues to study this unique system of gene transfer which has become a cornerstone of plant biotechnology.

In 1990, Gene Nester was awarded the inaugural Australia Prize along with an Australian and a German scientist for their work on *Agrobacterium* transformation of plants. In 1991, he was awarded the Cetus Prize in Biotechnology by the American Society of Microbiology. He has been elected to Fellowship in the National Academy of Sciences, the American Academy for the Advancement of Science, the American Academy of Microbiology, and the National Academy of Sciences in India. Throughout his career, Gene has been actively involved with the American Society for Microbiology in several leadership positions.

In addition to his research activities, Gene has taught an introductory microbiology course for students in the allied health sciences for many years. He wrote the original version of the present text, *Microbiology: Molecules, Microbes and Man*, with C. Evans Roberts, Brian McCarthy, and Nancy Pearsall more than 30 years ago because they felt no suitable text was available for this group of students. The original text pioneered the organ system approach to the study of infectious disease.

Gene enjoys traveling, museum hopping, and the study and collecting of Northwest Coast Indian Art. He and his wife, Martha, live on Lake Washington with their labradoodle, Twana, and a well-used kayak. Their two children and four grandchildren live in the Seattle area.



Denise Anderson

Denise Anderson is a Senior Lecturer in the Department of Microbiology at the University of Washington, where she teaches a variety of courses including general microbiology, recombinant DNA techniques, medical bacteriology laboratory, and medical mycology/parasitology laboratory. Equipped with a diverse educational background, including undergraduate work in nutrition and graduate work in food science and in microbiology, she first discovered a

passion for teaching when she taught microbiology laboratory courses as part of her graduate training. Her enthusiastic teaching style, fueled by regular doses of Seattle's famous caffeine, receives high reviews by her students.

Outside of academic life, Denise relaxes in the Phinney Ridge neighborhood of Seattle, where she lives with her husband, Richard Moore, and dog, Dudley (neither of whom are well trained). When not planning lectures, grading papers, or writing textbook chapters, she can usually be found chatting with the neighbors, fighting the weeds in her garden, or enjoying a fermented beverage at the local pub.



C. Evans Roberts, Jr.

Evans Roberts was a mathematics student at Haverford College when a chance encounter landed him a summer job at the Marine Biological Laboratory in Woods Hole, Massachusetts. There, interactions with leading scientists awakened an interest in biology and medicine. After finishing his degree at Haverford, he went on to get a M.D. degree at Columbia University College of Physicians and Surgeons, complete an internship at University of Rochester School of Medicine and Dentistry,

and a residency in medicine at University of Washington School of Medicine where he also completed a fellowship in Infectious Diseases under Dr. William M. M. Kirby, and a traineeship in Diagnostic Microbiology under Dr. John Sherris.

Subsequently, Dr. Roberts taught microbiology at University of Washington, University of Oregon, and Chiang Mai University, in Chiang Mai, Thailand, returning to University of Washington thereafter. He has directed diagnostic medical microbiology laboratories, served on hospital infection control committees, and taught infectious diseases to nurse practitioners in a camp for Karen refugees in Northern Thailand. He has had extensive experience in the practice of medicine as it relates to infectious diseases. He is certified both by the American Board of Microbiology and the American Board of Internal Medicine.

Evans Roberts worked with Gene Nester in the early development of *Microbiology: A Human Perspective*. His professional publications concern susceptibility testing as a guide to treatment of infectious diseases, etiology of Whipple's disease, group A streptococcal epidemiology, use of fluorescent antibody in diagnosis, bacteriocin typing, antimicrobial resistance in gonorrhea and tuberculosis, Japanese B encephalitis, and rabies. For relaxation, he enjoys hiking, bird watching and traveling worldwide.



Martha Nester

Martha Nester received an undergraduate degree in biology from Oberlin College and a Master's degree in education from Stanford University. She has worked in university research laboratories and has taught elementary school. She currently works in an environmental education program at the Seattle Audubon Society. Martha has worked with her husband, Gene, for more than 40 years on microbiology textbook projects, at first informally as an editor and sounding board, and then as one

of the authors of *Microbiology: A Human Perspective*. Martha's favorite activities include spending time with their four grandchildren, all of whom live in the Seattle area. She also enjoys playing the cello with a number of musical groups in the Seattle area.

PREFACE

This is an exciting yet challenging time to be teaching and learning about microbiology. The need to provide accurate and current information about the good and bad microbes seems greater than ever. Almost every day a newspaper article describes illness arising from a contaminated food, the discovery of microbes in an environment once considered impossible to sustain life, the sequencing of another microbial genome, or the death of an individual from a rare infectious disease. Anyone glancing at the front page cannot help but realize the impact that microorganisms have in our daily lives. The announcements of the many scientific advances being made about the microbial world often bring with them vehement arguments related to the science. Are plants that contain genes of microorganisms safe to eat? Is it wise to put antimicrobial agents in soaps and animal feed? What agents of biological warfare might endanger the citizens of the world? Are we facing another flu pandemic? This book presents what we believe are the most important facts and concepts about the microbial world and the important role its members play in our daily lives. With the information presented, students should be able to form reasoned opinions and discuss intelligently their views on these questions.

An important consideration in revising this textbook is the diverse interests among students who take an introductory microbiology course. As always, many students take microbiology as a prerequisite for nursing, pharmacy, and dental programs. A suitable textbook must provide a solid foundation in health-related aspects of microbiology, including coverage of medically important bacteria, antimicrobial medications, and immunization. An increasing number of students take microbiology as a step in the pursuit of other fields, including biotechnology, food science, and ecology. For these students, topics such as recombinant DNA technologies, fermentation processes, and microbial diversity are essential. With the recent outbreaks of foodborne illnesses traced to products that had been distributed widely, the subject of microbial identification becomes more relevant. Microbiology is also popular as an elective for biology students, who are particularly interested in topics that highlight the relevance of microorganisms in the biological world. Because of the wide range of career goals and interests of students, we have made a particular effort to maintain a broad scope, providing a balanced approach, yet retaining our strength in medical microbiology.

Diversity in the student population is manifested not only in the range of career goals, but also in educational backgrounds. For some, microbiology may be their first college-level science course; for others, microbiology builds on an already strong background in biology and chemistry. To address this broad range of student backgrounds, we have incorporated numerous learning

aids that will facilitate review for some advanced students, and will be a tremendous support to those who are seeing this material for the first time.

Preparing a textbook that satisfies such a broad range of needs and interests is a daunting task, but also extremely rewarding. We hope you will find that the approach and structure of this edition presents a modern and balanced view of microbiology in our world, acknowledging the profound and essential impact that microbes have on our lives today and their possible roles in our lives tomorrow.

Features of the Sixth Edition

Completely updated and including the most current topics in microbiology today, *Microbiology: A Human Perspective*, sixth edition, continues to be a classic. It has always been our goal to present sound scientific content that students can understand and rely upon for accuracy and currency, and thereby succeed in their preparation for meaningful careers. We have used constructive comments from numerous microbiology instructors and their students to continue to enhance the robust features of this proven text.

Expert Approach to Writing

We, as a strong and diverse team of scientists and teachers, solidly present the connection between microorganisms and humans. Because of our individual specializations and our research and educational backgrounds, we remain in the hub of the scientific community and can provide accurate and modern coverage spanning the breadth of microbiology. More importantly, as teachers, we constantly strive to present material that easily speaks to the students reading it.

We recognize that a textbook, no matter how exciting the subject matter, is not a novel. Few students will read the text from cover to cover and few instructors will include all of the topics covered in their course. We have used judicious redundancy to help present each major topic as a complete unit. We have avoided the chatty, superficial style of writing in favor of clarity and conciseness. The text is not “watered down” but rather provides students the depth of coverage needed to fully understand and appreciate the role of microorganisms in the biological sciences and human affairs.

“Without a doubt Microbiology: A Human Perspective is one of the most readable science texts I have ever had the pleasure of reading. The text is not scary or overly weighty in its approach to microbiology.”
(Robyn Senter, Lamar State College–Orange)

"I like the simple, straight-forward wording. An introductory student with no or little background in biology should have no problems understanding these concepts."
(Karen Nakaoka, Weber State University)

"Students can relate to the examples/analogies and apply them to their daily lives. The text clearly demonstrates the connection between microbes and humans!"
(Michelle Fisher, Three Rivers Community College)

Instructive Art Program that Speaks a Thousand Words

Microorganisms, by definition, are invisible to the naked eye. It becomes ever more important to allow students to visualize organisms as well as processes to reinforce learning. The art program continues as a key element of the learning process. Each figure in *Microbiology: A Human Perspective* was developed as the narrative was written and is referenced in bold in the supporting text. Colors and symbols are used consistently throughout the text. Legends are short, clear, and descriptive. Various types of art styles are used as needed to bring concepts to life.

Overview Figures simplify complex interactions and provide a sound study tool. **Image Pathways** help students follow the progression of a discussion over several pages by highlighting and visualizing in detail each step of an overview figure.

Process Figures include step-by-step descriptions and supporting text so that the figure walks through a compact summary of important concepts.

Combination Figures tie together the features that can be illustrated by an artist with the appearance of organisms in the real world.

Stunning Micrographs used generously throughout the text bring the microbial world to life. In the chapters presenting infectious diseases (chapters 22 to 29), micrographs are often combined with photographs showing the symptoms that the organisms cause.

Unmatched Clinical Coverage

Evans Roberts, Jr.—a member of the author team who is licensed and board certified in internal medicine by the American Board of Internal Medicine, and in public health and medical laboratory microbiology by the American Board of Microbiology—ensures that clinical coverage is accurate, modern, and instructive to those planning to enter health careers. The incomparable treatment of infectious diseases, which are organized by human body systems, is supported with generous photographs, summary tables, case histories, and critical thinking questions. Elements of the unparalleled clinical coverage include:

- Consistent coverage of all diseases, including individual sections that describe the symptoms, pathogenesis, causative agent, epidemiology, prevention, and treatment.
- Disease summaries that feature a drawing of a human showing symptoms, portals of entry and exit, location of pathology,

and a step-by-step description of the infection process for each major disease.

- Case presentations of realistic clinical situations.
- Modern coverage of topics such as emerging diseases, new vaccines, and nosocomial infections.
- Dedicated chapters covering wound infections and HIV.

Learning System that Actively Involves Students

In today's classroom, it is important to pursue active learning by students. This edition of *Microbiology* challenges students to think critically by providing several avenues of practice in analyzing data, drawing conclusions, synthesizing information, interpreting graphs, and applying concepts to practical situations. These learning tools, developed by critical thinking expert Robert Allen, will benefit students pursuing any discipline.

What's New In This Edition?

We moved the chapter on host-microbe interactions so that it now immediately follows the chapters on innate and adaptive immunity. This makes it easier for instructors to present a trilogy of topics: Part I, "The Immune Wars" (innate and adaptive immunity); Part II, "The Microbes Fight Back" (pathogenesis); and Part III, "The Return of the Humans" (vaccination, epidemiology, and antimicrobial medications). We also moved the chapter on respiratory infections forward. This puts the major discussion of *Streptococcus pyogenes* early in the infectious disease section, providing students with a solid framework to help them understand the additional coverage in subsequent chapters. The following are new features in each chapter. Other changes and updates include:

Chapter Highlights

Chapter 1

Humans and the Microbial World

- New figure showing advances in microbiology in the context of other historical events

Chapter 2

The Molecules of Life

- New section on molarity
- New table summarizing the characteristics of various sugars and their importance

Chapter 3

Microscopy and Cell Structure

- Description of the bacterial cytoskeleton has been added
- Lipid rafts in eukaryotic membranes are described
- New figure of a model bacterium emphasizing the layers that envelop the cell

Chapter 4

Dynamics of Prokaryotic Growth

- New table highlighting the impact of exponential growth
- The concept of limiting nutrients is described
- Updated figure and description of an anaerobe container

Chapter 5

Control of Microbial Growth

- New figure on membrane filtration

Chapter 6

Metabolism: Fueling Cell Growth

- The importance of microbial metabolism in the production of biofuels is discussed
- The description of the steps of glycolysis has been simplified by grouping them into two phases: investment and payoff

Chapter 7

The Blueprint of Life, from DNA to Protein

- New section describing the role of RNA interference in eukaryotic gene expression
- Alternative sigma factors are now discussed in the section on mechanisms to control transcription
- Figures showing quorum sensing and two component regulatory systems have been added

Chapter 8

Bacterial Genetics

- Reorganized to create a new section on mobile genetic elements, highlighting the importance of horizontal gene transfer
- New table that lists mobile genetic elements

Chapter 9

Biotechnology and Recombinant DNA

- Reorganized so that methods immediately follow applications
- In recognition of the fact that many of the applications of Southern Blotting have been replaced by PCR, information on the technique has been moved to the web
- Updated information and explanatory figure on DNA sequencing
- The Human Microbiome Project is described
- Discussion of metagenomics has been added

Chapter 10

Identification and Classification of Prokaryotic Organisms

- Updated boxed story on tracing an *E. coli* O157:H7 outbreak
- Updated example of the importance of distinguishing different strains of a species

Chapter 11

The Diversity of the Prokaryotic Organisms

- New description of *Epulopiscium*

- New description of *Wolbachia*

- New equations that emphasize the energy sources and terminal electron acceptors used by the microbes covered in the section on metabolic diversity

Chapter 12

The Eukaryotic Members of the Microbial World

- Revised figure on the anatomy of the mosquito
- New Future Challenge

Chapter 13

Viruses of Bacteria

- Expanded discussion on the importance of phage
- New figure on restriction-modification
- New Perspective on mimiviruses
- Revised figure on restriction-modification

Chapter 15

The Innate Immune Response

- New figure that illustrates how lymph is formed
- Neutrophil extracellular traps (NETs) are described

Chapter 16

The Adaptive Immune Response

- The importance of regulatory T cells in preventing autoimmune disease is included
- Information on the recently discovered T_H17 cells is included in the subsets of effector helper T cells

Chapter 17

Host-Microbe Interactions

- Moved chapter forward so that it directly follows the information about innate and adaptive immunity, emphasizing the importance of evading the immune response in pathogenesis
- Added description of the hygiene hypothesis
- New Future Challenge on probiotics

Chapter 18

Immunologic Disorders

- Added information on childhood allergies and bone marrow transplantation
- Revised sections on immunotherapy, transfusion reactions, and erythroblastosis fetalis

Chapter 19

Applications of the Immune Response

- New information about the HPV vaccine
- Mention of a lipid A derivative as a new adjuvant has been added
- New application question that directs student to the vaccine schedule on the CDC website

Chapter 20

Epidemiology

- Expanded Future Challenge on bioterrorism to include category A, B, and C agents
- Expanded and renamed section on nosocomial infections so that it now reflects the general concerns regarding healthcare-associated infections
- Updated coverage of Universal Precautions (Perspective 20.1)

Chapter 21

Antimicrobial Medications

- Information about entry inhibitors and integrase inhibitors in the section on antiviral medications has been added
- Added new information about glycylicyclines

Chapter 22

Respiratory Infections

- Moved this chapter topic to the beginning of the coverage of infectious diseases so that the complete description of *Streptococcus pyogenes* is now consolidated in the section on strep throat
- Consolidated material on *Streptococcus pyogenes* from other chapters
- Information on avian influenza has been added

Chapter 23

Skin Infections

- Consolidated material on *Staphylococcus aureus* from other chapters
- Added information on MRSA
- Added a photograph of individual with erythema infectiosum

Chapter 24

Wound Infections

- Added a new case presentation on gangrene

Chapter 25

Digestive System Infections

- Revised figure on *Helicobacter pylori* infection
- Photograph of individual with herpes simplex labialis has been added
- Revised figure on cholera mode of action
- Updated figures on mumps and hepatitis A

Chapter 26

Genitourinary Infections

- Updated information on herpes simplex latency, prevention of papilloma virus infection, and changes in the HIV/AIDS pandemic

Chapter 27

Nervous System Infections

- Added a new table on the causes of meningitis; updated illustrations on West Nile and invasive *Haemophilus influenzae*

Chapter 28

Blood and Lymphatic Infections

- Updated illustrations on tularemia, yellow fever, and malaria incidence

Chapter 29

HIV Disease and Complications of Immunodeficiency

- Updated information on HIV/AIDS distribution, deaths, impact on women
- Updated nomenclature for the causative agent of pneumocystosis
- Added normal comparison figure for CMV eye involvement

Chapter 30

Microbial Ecology

- Figure illustrating how dead zones develop has been added

Chapter 32

Food Microbiology

- Updated example of an *E. coli* O157:H7 outbreak

-Teaching and Learning Supplements- ARIS

The ARIS (Assessment, Review, and Instruction System) website that accompanies this textbook includes self-quizzing with immediate feedback, animations of key processes with self-quizzing, electronic flashcards to review key vocabulary, additional clinical case presentations and more—a whole semester's worth of study help for students. Instructors will find an instructor's manual, PowerPoint lecture outlines, and test questions that are directly tied to *Microbiology, 6/e* as well as a complete electronic homework management system where they can create and share course materials and assignments with colleagues in just a few clicks of the mouse. Instructors can also edit questions, import their own content, and create announcements and/or due dates for assignments. ARIS offers automatic grading and reporting of easy-to-assign homework, quizzing, and testing. Check out www.aris.mhhe.com, select your subject and textbook, and start benefiting today!

Presentation Center

Part of the ARIS website, the Presentation Center, contains assets such as photos, artwork, animations, PowerPoints, and other media resources that can be used to create customized lectures, visually enhance tests and quizzes, and design compelling course websites or attractive, printed support materials. All assets are copyrighted by McGraw-Hill Higher Education but can be used by instructors for classroom purposes. The visual resources in this collection include:

Art—Full-color digital files of all illustrations in the book can be readily imported into lecture presentations, exams, or custom-made classroom materials. In addition, all files are pre-inserted into blank PowerPoint slides for ease of lecture preparation.

Photos—The photos collection contains digital files of photographs from the text that can be reproduced for multiple classroom uses.

Tables—Every table that appears in the text has been saved in electronic form for use in classroom presentation and/or quizzes.

Animations—More than 50 full-color animations are available to harness the visual impact of processes in motion. Import these dynamic files into classroom presentations or online course materials.

Lecture Outlines—Specially prepared custom outlines for each chapter are offered in easy-to-use PowerPoint slides.

Online Computerized Test Bank

A comprehensive bank of test questions is provided within a computerized test bank powered by McGraw-Hill's flexible electronic testing program, EZ Test Online. EZ Test Online allows instructors to create and access paper or online tests and quizzes in an easy-to-use program anywhere, at any time, without installing the testing software. Now, with EZ Test Online, instructors can select questions from multiple McGraw-Hill test banks or author their own, and then either print the test for paper distribution or give it online.

Laboratory Manual

The sixth edition of *Microbiology Experiments: A Health Science Perspective*, by the late John Kley and by Mary Bicknell, has been prepared to directly support the text (although it may also be used with other microbiology textbooks). The laboratory manual features health-oriented experiments and endeavors that also reflect the goals and safety regulation guidelines of the American Society for Microbiology. Engaging student projects introduce some more intriguing members of the microbial world and expand the breadth of the manual beyond health-related topics. New experiments introduce modern techniques in biotechnology such as the use of restriction enzymes and use of a computer database to identify sequence information.

McGraw-Hill publishes additional microbiology laboratory manuals. Please contact your McGraw-Hill sales representative for more information.

Preparator's Manual for the Laboratory Manual

This invaluable guide includes answers to exercises, tips for successful experiments, lists of microbial cultures with sources and storage information, formulae and sources for stains and reagents, directions and recipes for preparing culture media, and sources of supplies. The *Preparator's Manual* is available to instructors through ARIS.

Transparencies

A set of acetate transparencies can be customized for your course. Please contact your McGraw-Hill sales representative for details.

Electronic Books

CourseSmart is a new way for faculty to find and review eTextbooks. It's also a great option for students who are interested in saving money by accessing their course materials digitally. CourseSmart offers thousands of the most commonly adopted textbooks across hundreds of courses from a wide variety of higher education publishers. It is the only place for faculty to review and compare the full text of a textbook online, providing immediate access without the environmental impact of requesting a print exam copy. At CourseSmart, students can save up to 50% off the cost of a print book, reduce their impact on the environment, and gain access to powerful web tools for learning including full text search, notes and highlighting, and email tools for sharing notes between classmates. www.CourseSmart.com

McGraw-Hill: Biology Digitized Video Clips

McGraw-Hill is pleased to offer adopting instructors an outstanding presentation tool—digitized biology video clips on DVD! Licensed from some of the highest-quality science video producers in the world, these brief segments range from about 5 seconds to just under 3 minutes in length and cover all areas of general biology from cells to ecosystems. Engaging and informative, McGraw-Hill's digitized videos will help capture students' interest while illustrating key biological concepts and processes such as Virus Lytic Cycle, Osmotic Effects on Blood Cells, and Anti-Immune Responses.

Course Delivery Systems

In addition to McGraw-Hill's ARIS course management options, instructors can also design and control their course content with help from our partners, WebCT, Blackboard, Top-Class, and eCollege. Course cartridges containing website content, online testing, and powerful student tracking features are readily available for use within these or any other HTML-based course management platforms.

— Reviewers of the Sixth Edition —

Gene Nester, Evans Roberts, Brian McCarthy, and Nancy Pearsall shared a vision many years ago to write a new breed of microbiology textbook especially for students planning to enter nursing and other health-related careers. Today there are other books of this type, but we were extremely gratified to learn that a majority of the students we surveyed intend to keep their copies of *Microbiology: A Human Perspective* because they feel it will benefit them greatly as they pursue their studies in these fields. Special thanks to the many students who used *Microbiology: A Human Perspective* over the years and who shared their thoughts with us about how to improve the presentation for the students who will use this edition of the text.

We offer our sincere appreciation to the many gracious and expert professionals who helped us with this revision by offering helpful suggestions. In addition to thanking those individuals listed here who carefully reviewed chapters, we also thank those who responded to our information surveys, those who participated

in regional focus groups, and those participants who chose not to be identified. All of you have contributed significantly to this work and we thank you.

Cynthia Anderson, *Mt. San Antonio College*
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We would also like to thank Denise's husband, Richard Moore, who was "forced" to proofread and critique many of the chapters. Although he has no formal scientific education, or perhaps because of that fact, his suggestions have been instrumental in making the text more "reader-friendly." Much to his own surprise, Richard has learned enough about the fundamentals of microbiology to actually become intrigued with the subject.

Special thanks to the reviewers and other instructors who helped guide us in this revision. Deciding what to eliminate, what to add, and what to rearrange is always difficult, so we appreciate your input.

Thanks also to Deborah Allen and David Hurley, who helped shape the book through their work on earlier editions. Deborah taught us the true meaning of excellence, both by example and through gentle guidance. David was instrumental in helping us navigate the murky waters during a substantial revision that updated the coverage of innate and adaptive immunity.

A list of acknowledgments is not complete without thanking the people from McGraw-Hill—Jim Connely, Lisa Bruflo, Tami Petsche, and Peggy Lucas—who gave inspiration and sound advice throughout this revision. Jayne Klein, Mary Jane Lampe, and our copyeditor, Sue Dillon, were instrumental in making sure the correct words actually made it onto paper.

Additionally, we would like to thank Joseph Gauthier, Elizabeth McPherson, and Donald Rubbelke for producing new media resources to support us and other instructors who lecture from our text.

We hope very much that this text will be interesting, educational for students, a help to their instructors, and will convey the excitement that we all feel for the subject. We would appreciate any comments and suggestions from our readers.

Eugene Nester
Denise Anderson
C. Evans Roberts, Jr.
Martha Nester

GUIDED TOUR

Instructive Artwork Makes the Difference

A picture is worth a thousand words, especially in microbiology. *Microbiology: A Human Perspective* employs a combination of art styles to bring concepts to life and to provide concrete, visual reinforcement of the topics discussed throughout the text.

Overview Figures

Overview figures simplify complex interactions and provide a sound study tool.

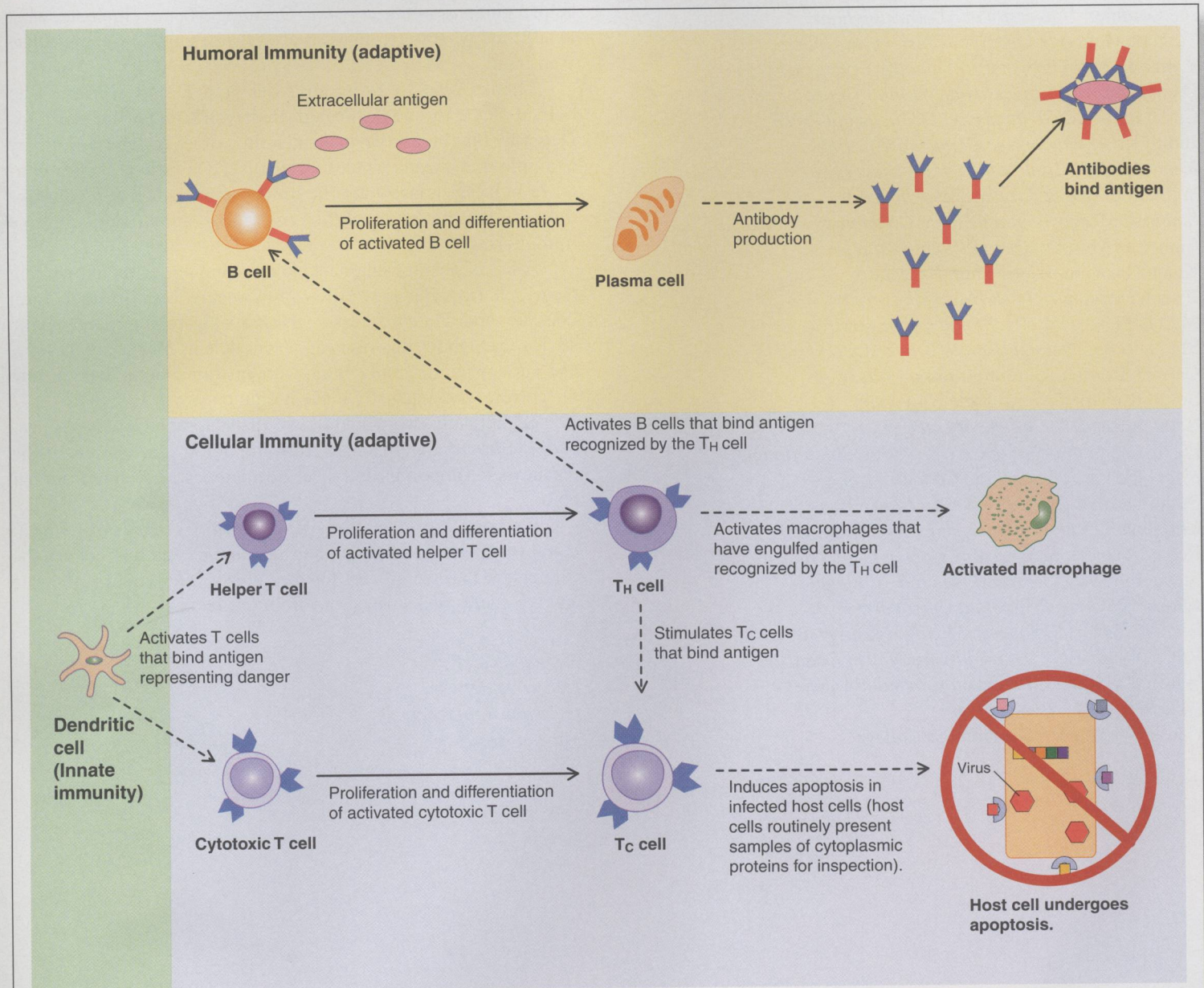


FIGURE 16.1 Overview of Humoral and Cellular Immunity Memory cells are not shown in this diagram. Cellular immunity is also called cell-mediated immunity (CMI).

Image Pathways

Image pathways help students follow the progression of a discussion over several pages by highlighting and illustrating each step of an overview figure.

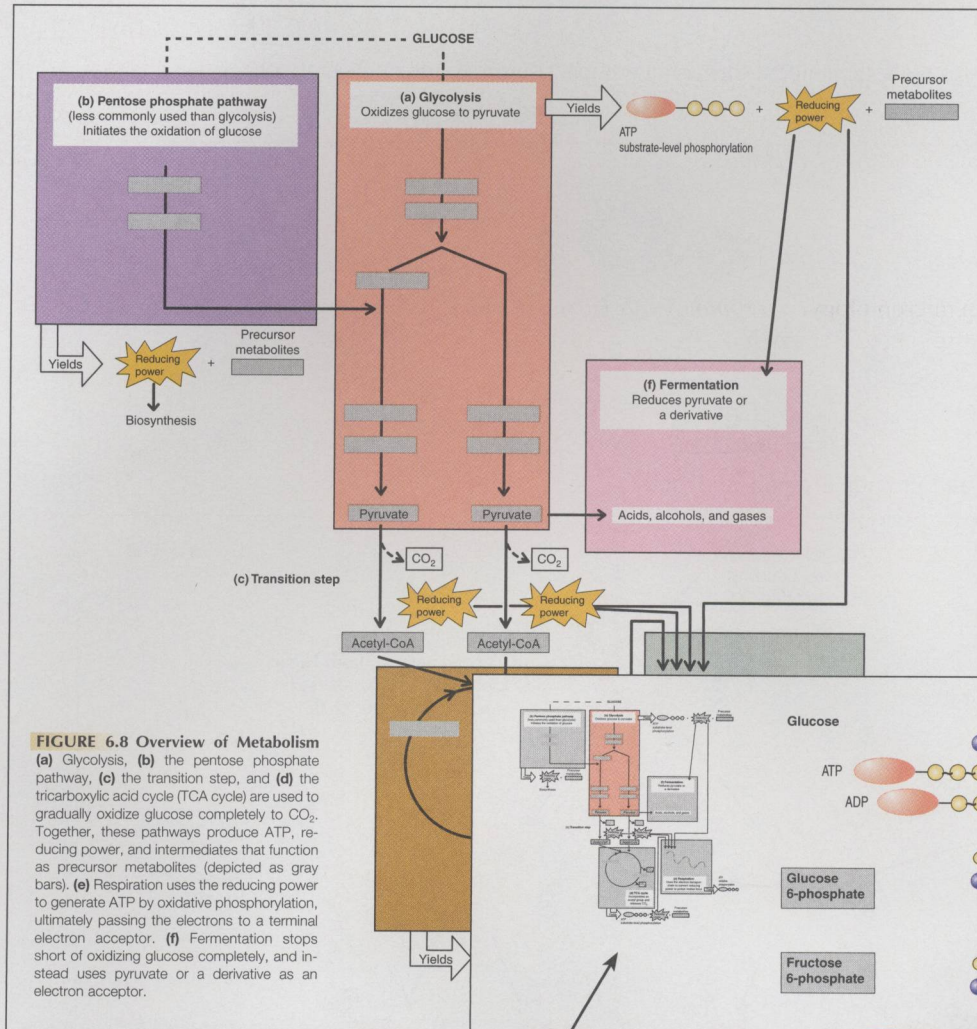


FIGURE 6.8 Overview of Metabolism (a) Glycolysis, (b) the pentose phosphate pathway, (c) the transition step, and (d) the tricarboxylic acid cycle (TCA cycle) are used to gradually oxidize glucose completely to CO_2 . Together, these pathways produce ATP, reducing power, and intermediates that function as precursor metabolites (depicted as gray bars). (e) Respiration uses the reducing power to generate ATP by oxidative phosphorylation, ultimately passing the electrons to a terminal electron acceptor. (f) Fermentation stops short of oxidizing glucose completely, and instead uses pyruvate or a derivative as an electron acceptor.

The overview figure is shown in the image pathways to help students follow a process through each step.

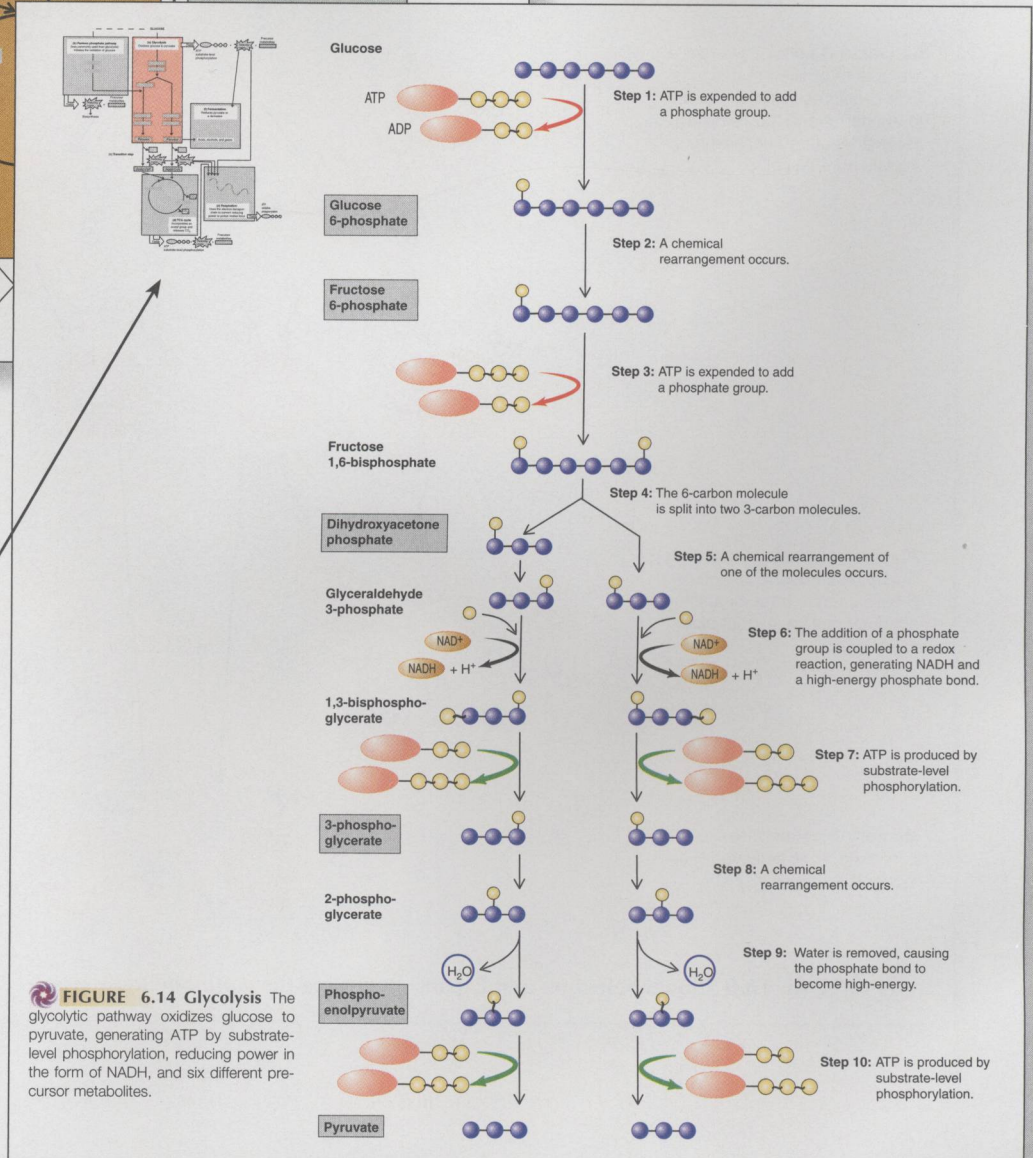
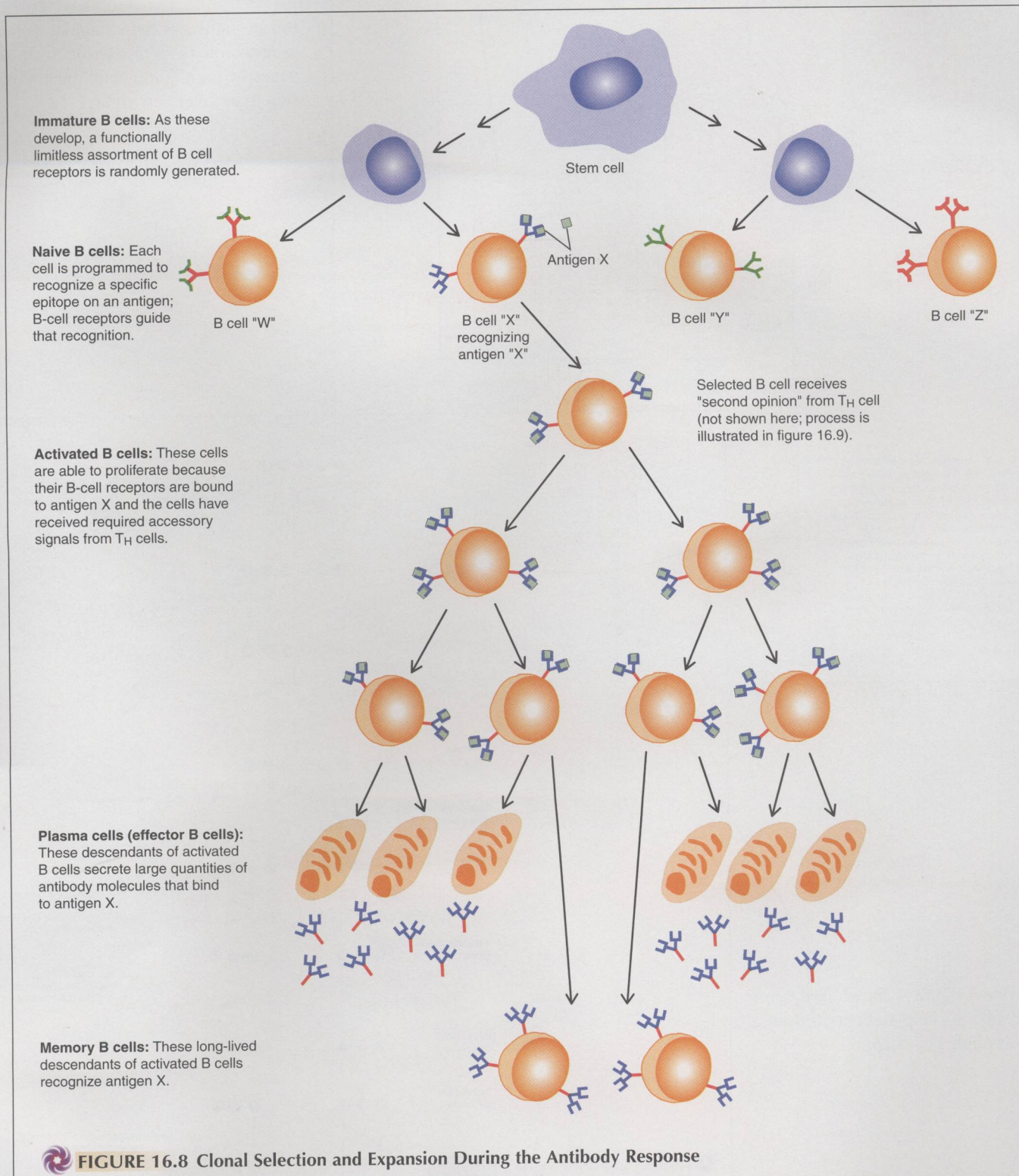


FIGURE 6.14 Glycolysis The glycolytic pathway oxidizes glucose to pyruvate, generating ATP by substrate-level phosphorylation, reducing power in the form of NADH, and six different precursor metabolites.

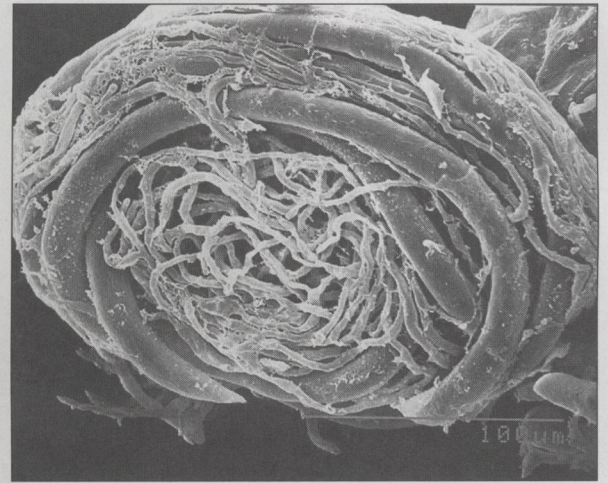
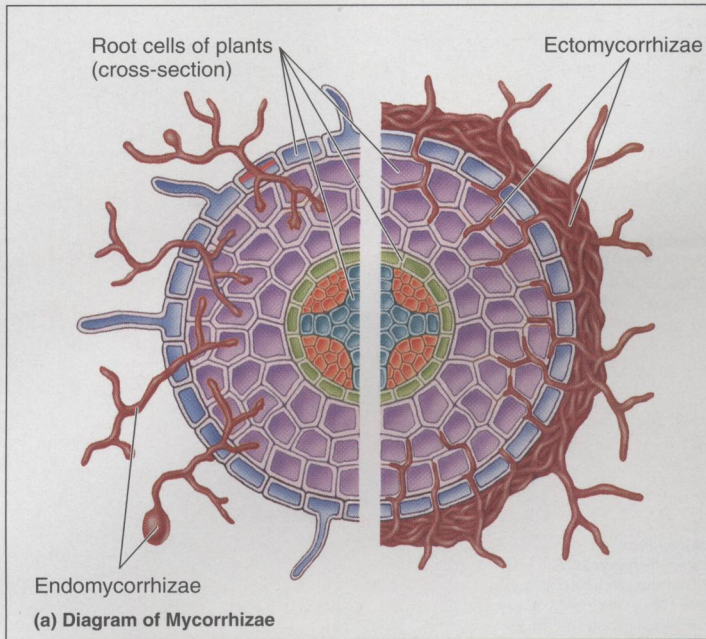
Process Figures

Process figures include step-by-step descriptions to walk the student through a compact summary of important concepts.

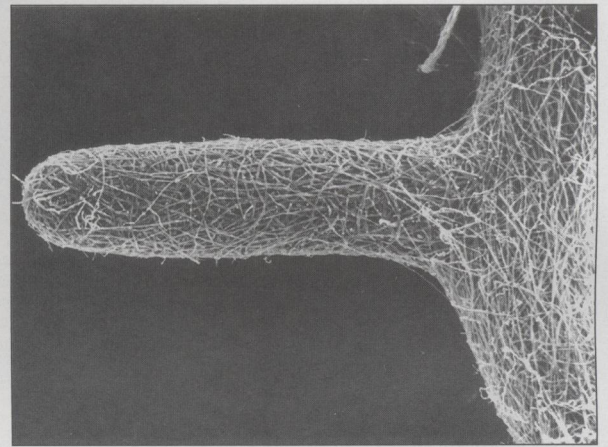


Combination Figures

Combination figures tie together the appearance of organisms in the real world with features that can be illustrated by an artist.



(b) Endomycorrhiza



(c) Ectomycorrhiza

Micrographs

Stunning micrographs used generously throughout the text bring the microbial world to life.

