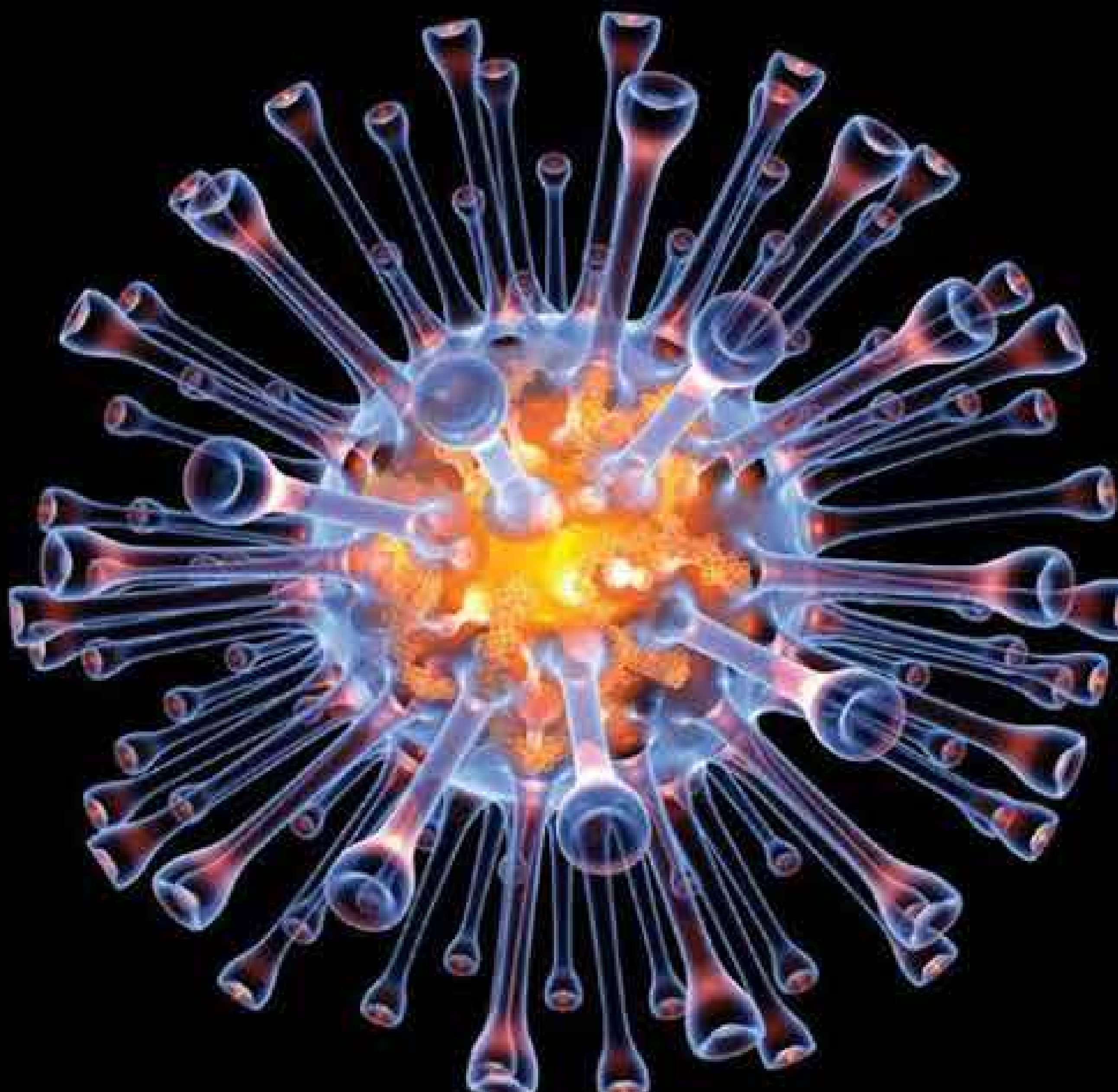
MICROBIOLOGY
PRINCIPLES AND EXPLORATIONS

9th EDITION



JACQUELYN G. BLACK | LAURA J. BLACK

WILEY

Diseases and the Organisms that Cause Them

BACTERIAL DISEASES—ALSO SEE APPENDIX B

Disease	Organism	Type*	Page
acne	*Propionibacterium acnes*	R, +	591
actinomycosis	*Actinomyces israelii*	I, +	603
anthrax	*Bacillus anthracis*	R, +	95, 740–744
bacterial meningitis	*Haemophilus influenzae*	R, –	775
	Neisseria meningitidis	C, –	451, 774
	Streptococcus pneumoniae	C, +	775
	Listeria monocytogenes	R, –	775
bacterial vaginitis	*Gardnerella vaginalis*	R, –	624
botulism	*Clostridium botulinum*	R, +	420, 699, 785–787
brucellosis (undulant fever, Malta fever)	*Brucella* sp.†	CB, –	747–748
cat scratch fever	*Afipia felis*, *Bartonella henselae*	R, – CB, NA	609
chancroid	*Haemophilus ducreyi*	R, –	634
cholera (Asiatic cholera)	*Vibrio cholerae*	vibrio, –	420, 703–705
conjunctivitis	*Haemophilus aegyptius*	CB, –	603
dental caries	*Streptococcus mutans*	C, +	693–695
diptheria	*Corynebacterium diptheriae*	R, +	656–658
ehrlichiosis	*Ehrlichia* sp.	R,NA	754
endocarditis	*Enterococcus faecalis*	C, +	737–738
food poisoning	*Staphylococcus aureus*	C, +	420, 698–699
	Streptococcus pyogenes	C, +	734
	Clostridium perfringens	R, +	420, 699
	Clostridium botulinum	R, +	699
	Bacillus cereus	R, +	699
	Listeria monocytogenes	R, +	775
	Campylobacter sp.	R, –	399, 699–705
	Shigella sp.	R, –	420, 701–703
	Salmonella sp.	R, –	398, 700–701
	Vibrio parahaemolyticus	R, –	705–706
gas gangrene	*Clostridium perfringens* and others	R, –	608–609
gonorrhea	*Neisseria gonorrhoeae*	C, –	627–630
granuloma inguinale (donovanosis)	*Calymmatobacterium granulomatis*	R, –	638
Hansen's disease (leprosy)	*Mycobacterium leprae*	R, A-F	414, 782–784
Legionnaires' disease (legionellosis)	*Legionella pneumophilia*	R, –	665–666
leptospirosis	*Leptospira interrogans*	S, –	624
listeriosis	*Listeria monocytogenes*	R, +	775
Lyme disease	*Borrelia burgdorferi*	S, –	339, 748–751
lymphogranuloma venereum	*Chlamydia trachomatis*	coccoid, NA	637–638
Madura foot (maduromycosis)	*Actinomadura, Streptomyces, Nocardia*	I, +, some A-F	603
nongonococcal urethritis (NGU)	*Chlamydia trachomatis*	R,VAR	636
	Ureaplasma urealyticum	I,NA	636–637
ornithosis (psittacosis)	*Chlamydia psittaci*	coccoid, NA	670
Oroyo fever (Carrion's disease, bartonellosis)	*Bartonella bacilliformis*	coccoid, –	754
peptic ulcer	*Helicobacter pylori*	R, –	707–708
periodontal disease	*Porphyromonas gingivalis* and others	R, –	696–697
pharyngitis (strep throat)	*Streptococcus pyogenes*	C, +	655–656
plague (black death) bubonic plague	*Yersinia pestis*	R, –	339, 744–746
pneumonic plague			745
pneumonia	*Streptococcus pneumoniae*	C, +	663–664
	Klebsiella pneumoniae	R, –	127, 170, 664, 684
pneumonia, atypical (walking pneumonia)	*Mycoplasma pneumoniae*	I,NA	664
pseudomembranous colitis	*Clostridium difficile*	R, +	708
puerperal fever (childbed fever)	*Streptococcus pyogenes*	C, +	736
Q fever	*Coxiella burnetti*	CB, NA	339, 671–672
rat bite fever	*Spirillum minor*	S, –	609–610
	Streptobacillus moniliformis	R, –	609–610
relapsing fever	*Borrelia* sp.	S, –	748
rheumatic fever	*Streptococcus pyogenes*	C, +	736–737
rickettsialpox	*Rickettsia akari*	CB, NA	754
Rocky Mountain spotted fever	*Rickettsia rickettsii*	CB, NA	753–754
salmonellosis	*Salmonella* sp.	R, –	700–701
shigellosis (bacillary dysentery)	*Shigella* sp.	R, –	701–703
skin and wound infections (scalded skin syndrome, scarlet fever, erysipelas, impetigo, etc.)	*Staphylococcus aureus*	C, +	589
	Staphylococcus epidermidis	C, +	589
	Streptococcus sp.	C, +	590
	Providencia stuartii	R, –	591
	Pseudomonas aeruginosa	R, –	591
	Serratia marcescens	R, –	199, 591
syphilis	*Treponema pallidum*	S, –	631–634
tetanus	*Clostridium tetani*	R, +	784–785
toxic shock syndrome	*Staphylococcus aureus*	C, +	625–626
trachoma	*Chlamydia trachomatis*	coccoid, NA	603
trench fever	*Rochalimaea quintana*	CB, NA	339, 754
tuberculosis	*Mycobacterium tuberculosis*	R, A-F	666–667
tuberculosis, avian	*Mycobacterium avium*	R, A-F	666
tularemia	*Francisella tularensis*	R, –	339, 746–747
typhoid fever	*Salmonella typhi*	R, –	701
typhus, endemic (murine typhus)	*Rickettsia typhi*	CB,NA	751–752
typhus, epidemic	*Rickettsia prowazekii*	CB,NA	752
typhus, recrudescent (Brill-Zinsser disease)	*Rickettsia prowazekii*	CB,NA	752
typhus, scrub (tsutsugamushi disease)	*Rickettsia tsutsugamushi*	CB,NA	752

Diseases and the Organisms that Cause Them (*Continued*)

BACTERIAL DISEASES—ALSO SEE APPENDIX B

Disease	Organism	Type*	Page
verruga peruana (bartonellosis)	*Bartonella bacilliformis*	coccoid, −	754
vibriosis	*Vibrio parahaemolyticus*	R, −	705
whooping cough (pertussis)	*Bordetella pertussis*	CB, −	660–663
yersiniosis	*Yersinia enterocolitica*	R, −	707

*Key to types:

C = coccus	I = irregular	VAR = Gram-variable
CB = coccobacillus	− = Gram-negative	A-F = acid-fast
R = rod	+ = Gram-positive	NA = not applicable
S = spiral		

†Species

VIRAL DISEASES

Disease	Virus	Reservoir	Page
aplastic crisis in sickle cell anemia	erythrovirus (B19)	humans	760
avian (bird) flu	influenza	birds	672–676
bronchitis, rhinitis	parainfluenza	humans, some other mammals	659–660
Burkitt's lymphoma	Epstein-Barr	humans	757–759
cervical cancer	human papillomavirus	humans	279, 598, 644
chickenpox	varicella-zoster	humans	284–287, 595–596
coryza (common cold)	rhinovirus	humans	278, 659
	coronavirus	humans	658–659
cytomegalic inclusion disease	cytomegalovirus	humans	644
Dengue fever	Dengue	humans	240, 755–756
encephalitis	Colorado tick fever	mammals	240, 760–761
	Eastern equine encephalitis	birds	278, 436, 779
	St. Louis encephalitis	birds	779
	Venezuelan equine encephalitis	rodents	278, 779
	Western equine encephalitis	birds	278, 339, 437, 779
epidemic keratoconjunctivitis	adenovirus	humans	605–606
fifth disease (erythema infectiosum)	erythrovirus (B19)	humans	279, 760
hantavirus pulmonary syndrome	bunyavirus	rodents	279, 681
hemorrhagic fever	Ebola virus (filovirus)	humans (?)	279, 759
	Marburg virus (filovirus)	humans (?)	279, 759
hemorrhagic fever, Bolivian	arenavirus	rodents and humans	760
hemorrhagic fever, Korean	bunyavirus (Hantaan)	rodents	279, 759–760
hepatitis A (infectious hepatitis)	hepatitis A	humans	278, 711–713
hepatitis B (serum hepatitis)	hepatitis B	humans	279, 713–715
hepatitis C (non-A, non-B)	hepatitis C	humans	715
hepatitis D (delta hepatitis)	hepatitis D	humans	715
hepatitis E (enterically transmitted non-A, non-B, non-C)	hepatitis E	humans	715
herpes, genital	usually herpes simplex type 2, sometimes type 1	humans	279, 640–642
herpes, oral	usually herpes simplex type 1, sometimes type 2	humans	279, 639
HIV disease, AIDS	human immunodeficiency virus (HIV)	humans	278, 564–571
infectious mononucleosis	Epstein-Barr	humans	757
influenza	influenza	swine, humans (type A)	278, 282, 523, 673–677
		humans (type B)	278, 282, 523, 673–677
		humans (type C)	774, 673–677
Lassa fever	arenavirus	rodents	760
measles (rubeola)	measles	humans	278, 641, 781
meningoencephalitis	herpes	humans	641, 781
molluscum contagiosum	poxvirus group	humans	598
monkeypox	orthopoxvirus	humans, monkeys	597
mumps	paramyxovirus	humans	697–698
pneumonia	adenoviruses, respiratory syncytial virus	humans	663–664
poliomyelitis	poliovirus	humans	278, 787–789
rabies	rabies	all warm-blooded animals	776–779
respiratory infections	adenovirus	humans	684
	polyomavirus	none	781
Rift Valley fever	bunyavirus (phlebovirus)	humans sheep, cattle	759–760
roseola	human herpes virus-6	humans	595
rubella (German measles)	rubella	humans	278, 593–594
SARS (sudden acute respiratory syndrome)	coronavirus	animal	679–680
shingles	varicella-zoster	humans	279, 595–596
smallpox	variola (major and minor)	humans	279, 596–597
viral enteritis	rotavirus	humans	679–681
warts, common (papillomas)	human papillomavirus	humans	279, 598–599
warts, genital (condylomas)	human papillomavirus	humans	279, 598–599, 642–643
West Nile	West Nile	birds	779–780
yellow fever	yellow fever	monkeys, humans, mosquitoes	278, 281, 340 756–757

The tables of fungal and parasitic diseases appear on the following page.

Diseases and the Organisms that Cause Them (*Concluded*)

UNCONVENTIONAL AGENTS

Disease	Agent	Resevior	Page
chronic wasting disease	prion	elk, deer	791
Creutzfeldt-Jacob disease	prion	humans	789–791
kuru	prion	humans	790
mad cow disease (bovine spongiform encephalopathy)	prion	cattle	791
scrapie	prion	sheep	790–791

FUNGAL DISEASES

Disease	Organism	Page
aspergillosis	*Aspergillus* sp	601, 683
blastomycosis	*Blastomyces dermatitidis*	601–602
candidiasis	*Candida albicans*	602
coccidioidomycosis (San Joaquin valley fever)	*Coccidioides immitis*	681–682
cryptococcosis	*Filobasidiella neoformans*	682–683
ergot poisoning	*Claviceps purpurea*	836
histoplasmosis	*Histoplasma capsulatum*	682
Pneumocystis pneumonia	*Pneumocystis carinii*	683
ringworm (tinea)	various species of *Epidermophyton, Trichophyton, Microsporum*	600–601
sporotrichosis	*Sporothrix schenckii*	601
zygomycosis	*Rhizopus* sp., *Mucor* sp	602

PARASITIC DISEASES

Disease	Organism	Type	Page
Acanthamoeba keratitis	*Acanthamoeba culbertsoni*	protozoan	445
African sleeping sickness (trypanosomiasis)	*Trypanosoma brucei gambiense* and *T. brucei rhodesiense*	protozoan	339–340, 792–793
amoebic dysentery	*Entamoeba histolytica*	protozoan	715–717
ascariasis	*Ascaris lumbricoides*	roundworm	724–725
babesiosis	*Babesia microti*	protozoan	765–766
balantidiasis	*Balantidium coli*	protozoan	715–717
Chagas' disease	*Trypanosoma cruzi*	protozoan	339, 793–796
chigger dermatitis	*Trombicula* sp.	mite	610
chigger infestation	*Tunga penetrans*	sandflea	610
Chinese liver fluke	*Clonorchis sinensis*	flatworm	720
crab louse	*Phthirus pubis*	louse	611
cryptosporidiosis	*Cryptosporidium* sp.	protozoan	716
dracunculiasis (Guinea worm)	*Dracunculus medinensis*	roundworm	333, 603
elephantiasis (filariasis)	*Wuchereria bancrofti*	roundworm	333, 740
fasciolopsiasis	*Fasciolopsis buski*	flatworm	719
giardiasis	*Giardia intestinalis*	protozoan	715–717
heartworm disease	*Dirofilaria immitis*	roundworm	313, 735
hookworm	*Ancylostoma duodenale* (Old World hookworm)	roundworm	724–725
	Necator americanus (New World hookworm)	roundworm	725
leishmaniasis kala azar oriental sore	*Leishmania braziliensis, L. donovani, L. tropica*	protozoan	339, 761
liver/lung fluke (paragonimiasis)	*Paragonimus westermani*	flatworm	329, 683
loaiasis	*Loa loa*	roundworm	333, 607
malaria	*Plasmodium* sp.	protozoan	318, 450, 762–765
pediculosis (lice infestation)	*Pediculus humanus*	louse	611
pinworm	*Enterobius vermicularis*	roundworm	725
river blindness (onchocerciasis)	*Onchocerca volvulus*	roundworm	606–607
scabies (sarcoptic mange)	*Sarcoptes scabiei*	mite	610–611
schistosomiasis	*Schistosoma* sp.	flatworm	331, 738–740
sheep liver fluke (fascioliasis)	*Fasciola hepatica*	flatworm	719–720
strongyloidiasis	*Strongyloides stercoralis*	roundworm	724–725
swimmer's itch	*Schistosoma* sp.	flatworm	603
tapeworm infestation (taeniasis)	*Hymenolepsis nana* (dwarf tapeworm)	flatworm	720–722
	Taenia saginata (beef tapeworm)	flatworm	330, 332, 720–722
	Taenia solium (pork tapeworm)	flatworm	720–722
	Diphyllobothrium latum (fish tapeworm)	flatworm	720–722
	Echinococcus granulosus (dog tapeworm)	flatworm	720–722
toxoplasmosis	*Toxoplasma gondii*	protozoan	765
trichinosis	*Trichinella spiralis*	roundworm	332, 722–723
trichomoniasis	*Trichomonas vaginalis*	protozoan	626–627
trichuriasis (whipworm)	*Trichuris trichiura*	roundworm	725–726
visceral larva migrans	*Toxocara* sp.	roundworm	725–726

This page intentionally left blank

MICROBIOLOGY

PRINCIPLES AND EXPLORATIONS

9 TH EDITION

JACQUELYN G. BLACK
Marymount University, Arlington, Virginia

LAURA J. BLACK

Laura Black has been working on this book since she was ten years old. She has been a contributing author for the past two editions and is now a coauthor of this ninth edition.

JACQUELYN and LAURA BLACK

WILEY

TO ROBERT . . .
for sharing his mother and grandmother with that greedy sibling "the book."

VICE PRESIDENT AND EXECUTIVE PUBLISHER Kaye Pace
SENIOR ACQUISITIONS EDITOR Bonnie Roth
SPONSORING EDITOR Joan Kalkut
ASSISTANT EDITOR Julia Nollen
EDITORIAL ASSISTANT Chloe Moffett
EXECUTIVE MARKETING MANAGER Clay Stone
SENIOR PRODUCT DESIGNER Brian Moriarty
DESIGN DIRECTOR Harry Nolan
TEXT AND COVER DESIGNER Wendy Lai
SENIOR PHOTO EDITOR Mary Ann Price
PHOTO RESEARCHER Ramón Rivera Moret
SENIOR CONTENT MANAGER Kevin Holm
SENIOR PRODUCTION EDITOR Elizabeth Swain
COVER IMAGE: Pasieka/Science Source. Computer artwork of a swine influenza (flu) virus particle. At the core of the virus is RNA (ribonucleic acid, orange) genetic material. This is surrounded by a nucleocapsid and a lipid envelope. In the envelope are two types of protein spike, hemagglutinin (H) and neuraminidase (N), which determine the strain of virus. These are used for recognizing and binding to the host cell.
AUTHOR PHOTO: Paul D. Robertson

This book was set in 10/12 Times Ten by codeMantra. The text and cover were printed and bound by Quad Graphics Versailles.

This book is printed on acid free paper. ∞

Founded in 1807, John Wiley & Sons, Inc. has been a valued source of knowledge and understanding for more than 200 years, helping people around the world meet their needs and fulfill their aspirations. Our company is built on a foundation of principles that include responsibility to the communities we serve and where we live and work. In 2008, we launched a Corporate Citizenship Initiative, a global effort to address the environmental, social, economic, and ethical challenges we face in our business. Among the issues we are addressing are carbon impact, paper specifications and procurement, ethical conduct within our business and among our vendors, and community and charitable support. For more information, please visit our website: www.wiley.com/go/citizenship.

Library of Congress Cataloging-in-Publication Data

Black, Jacquelyn G., Black, Laura J.
Microbiology: principles and explorations/Jacquelyn G. Black.—9th ed.
p. cm.
Includes index.
Main ISBN 978-1-118-74316-4
Binder version ISBN 978-1-118-91458-8

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

Preface

The development of microbiology—from Leeuwenhoek's astonished observations of "animalcules," to Pasteur's first use of rabies vaccine on a human, to Fleming's discovery of penicillin, to today's race to develop an AIDS vaccine is one of the most dramatic stories in the history of science. To understand the roles microbes play in our lives, including the interplay between microorganisms and humans, we must examine, learn about, and study their world—the world of microbiology.

Microorganisms are everywhere. They exist in a range of environments from mountains and volcanoes to deep-seas vents and hot springs. Microorganisms can be found in the air we breathe, in the food we eat, and even within our own body. In fact, we come in contact with countless numbers of microorganisms every day. Although some microbes can cause disease, most are not disease producers; rather they play a critical role in the processes that provide energy and make life possible. Some even prevent disease, and others are used in attempts to cure disease. Because microorganisms play diverse roles in the world, microbiology continues to be an exciting and critical discipline of study. And because microbes affect our everyday lives, microbiology provides many challenges and offers many rewards. Look at your local newspaper, and you will find items concerning microbiology: to mention a few, reports on diseases such as AIDS, tuberculosis, and cancer; the resurgence of malaria and dengue fever, or "new" diseases.

Did you know that the microbes in your gut (the gut microbiome) affect you even before you are born? If your mother was obese during pregnancy, she had a low diversity of microbes in her gut, which she will pass on to you setting the stage for development of obesity and diabetes later in you. As a woman approaches her delivery date, beneficial microbes migrate down to the birth canal where they will hopefully be passed on to her baby. But if it is premature or born by Caesarian section, it won't get them. Even the milk of C-sectioned mothers lacks proper diversity of microbes–and it won't catch up to normal for 6 months. But if the mother has been in labor for some hours before the C-section is done, the milk will be normal from day one. Hard labor causes a leaky gut which allows microbes to get into the circulation and reach the breast milk. So when you plan to have a baby, think of the microbial implications: lose weight before you get pregnant, don't have unnecessary C-sections, and breast feed. Those microbes are important.

One of the most exciting and controversial new developments occurred 5 years ago, when J. Craig Venter (of Human Genome fame) made a synthetic bacterium (*Synthia laboratorium*). Was he usurping the role of God? Did we have to fear a whole new horde of man-made bacteria which would ruin the environment, create new diseases, or set off huge epidemics? Or, would they be the answer to problems such as providing biofuels that would take care of energy needs? Read about Dr. Venter's work in Chapter 10. Incidentally, he already created the first synthetic virus a few years ago, from parts that he ordered from biological supply houses.

NAVIGATING MICROBIOLOGY

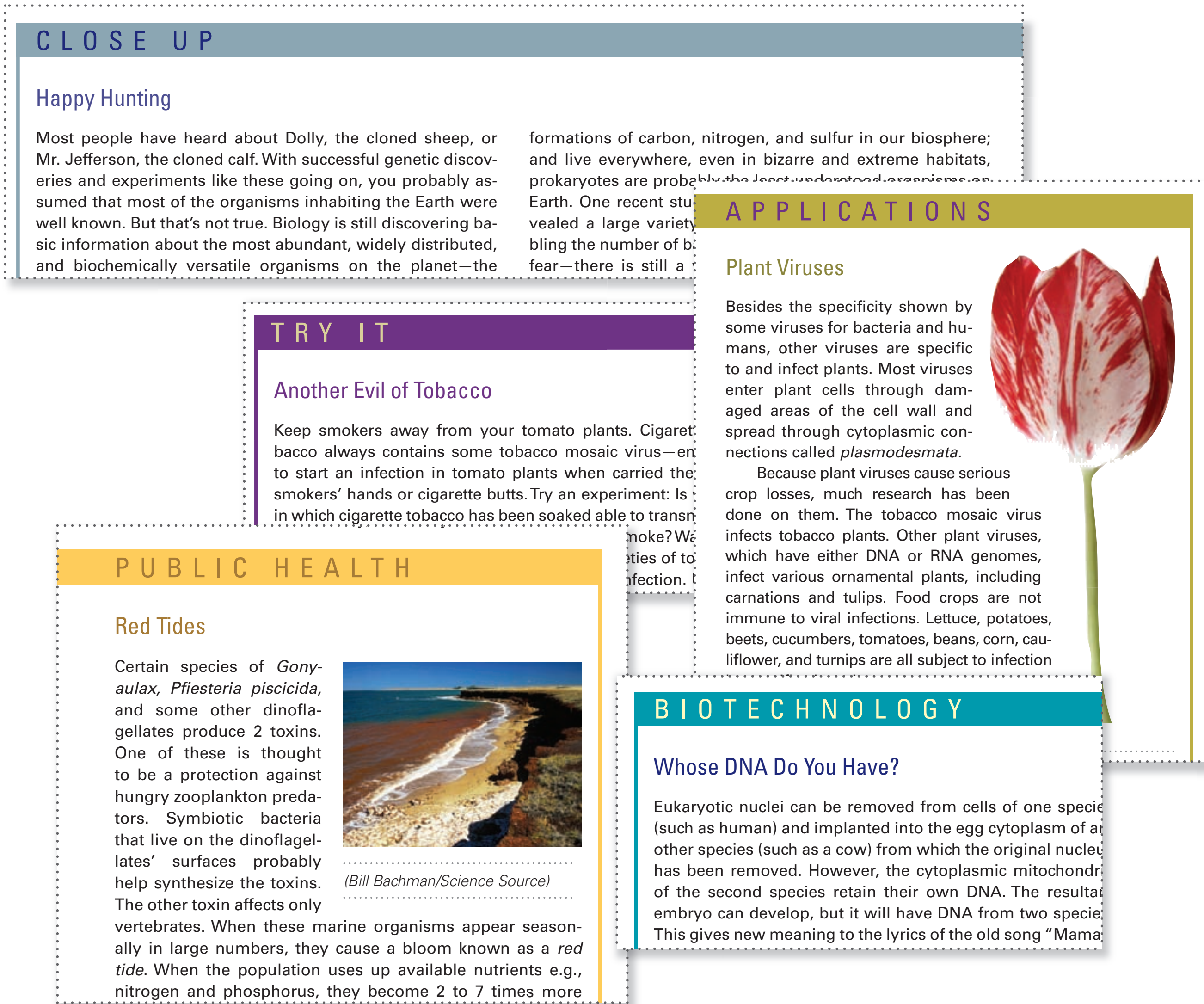
The theme that permeates this book is that microbiology is a current, relevant, exciting central science that affects all of us. I would like to share this excitement with you. Come with me as I take you, and your students, on a journey through the relevancy of microbiology. In countless areas—from agriculture to evolution, from ecology to dentistry—microbiology is contributing to scientific knowledge as well as solving human problems. Accordingly, a goal of this text is to offer a sense of the history of this science, its methodology, its many contributions to humanity, and the many ways in which it continues to be on the cutting edge of scientific advancement.

AUDIENCE AND ORGANIZATION

This book meets the needs of students in the health sciences as well as biology majors and students enrolled in other science programs who need a solid foundation in microbiology. It is designed to serve both audiences—in part by using an abundance of clinically important information to illustrate the general principles of microbiology and in part by offering a wide variety of additional applications.

In this edition, boxed essay titles appear in a different color to help students easily identify the type of application.

The organization of the ninth edition continues to combine logic with flexibility. The chapters are grouped in units from the fundamentals of chemistry, cells, and microscopy; to metabolism, growth, and genetics; to taxonomy of microbes and multicellular parasites; to control of microorganisms; to host-microbe interactions; to infectious diseases of humans; and finally to environmental



CLOSE UP

Happy Hunting

Most people have heard about Dolly, the cloned sheep, or Mr. Jefferson, the cloned calf. With successful genetic discoveries and experiments like these going on, you probably assumed that most of the organisms inhabiting the Earth were well known. But that's not true. Biology is still discovering basic information about the most abundant, widely distributed, and biochemically versatile organisms on the planet—the formations of carbon, nitrogen, and sulfur in our biosphere; and live everywhere, even in bizarre and extreme habitats, prokaryotes are proba… Earth. One recent stu… vealed a large variety… bling the number of b… fear—there is still a …

APPLICATIONS

Plant Viruses

Besides the specificity shown by some viruses for bacteria and humans, other viruses are specific to and infect plants. Most viruses enter plant cells through damaged areas of the cell wall and spread through cytoplasmic connections called *plasmodesmata*.

Because plant viruses cause serious crop losses, much research has been done on them. The tobacco mosaic virus infects tobacco plants. Other plant viruses, which have either DNA or RNA genomes, infect various ornamental plants, including carnations and tulips. Food crops are not immune to viral infections. Lettuce, potatoes, beets, cucumbers, tomatoes, beans, corn, cauliflower, and turnips are all subject to infection

TRY IT

Another Evil of Tobacco

Keep smokers away from your tomato plants. Cigaret… bacco always contains some tobacco mosaic virus—en… to start an infection in tomato plants when carried the… smokers' hands or cigarette butts. Try an experiment: Is … in which cigarette tobacco has been soaked able to transm… …moke? We… …ties of to… …fection. …

PUBLIC HEALTH

Red Tides

Certain species of *Gonyaulax, Pfiesteria piscicida*, and some other dinoflagellates produce 2 toxins. One of these is thought to be a protection against hungry zooplankton predators. Symbiotic bacteria that live on the dinoflagellates' surfaces probably help synthesize the toxins. The other toxin affects only vertebrates. When these marine organisms appear seasonally in large numbers, they cause a bloom known as a *red tide*. When the population uses up available nutrients e.g., nitrogen and phosphorus, they become 2 to 7 times more

(Bill Bachman/Science Source)

BIOTECHNOLOGY

Whose DNA Do You Have?

Eukaryotic nuclei can be removed from cells of one specie… (such as human) and implanted into the egg cytoplasm of a… other species (such as a cow) from which the original nucle… has been removed. However, the cytoplasmic mitochondri… of the second species retain their own DNA. The resulta… embryo can develop, but it will have DNA from two specie… This gives new meaning to the lyrics of the old song "Mama…

and applied microbiology. The chapter sequence will be useful in most microbiology courses as they are usually taught. However, it is not essential that chapters be assigned in their present order; it is possible to use this book in courses organized along different lines.

STYLE AND CURRENCY

In a field that changes so quickly—with new research, new drugs, and even new diseases—it is essential that a text be as up-to-date as possible. This book incorporates the latest information on all aspects of microbiology, including geomicrobiology, phage therapy, deep hot biosphere vents, and clinical practice. Special attention has been paid to such important, rapidly evolving topics as genetic engineering, gut microbiome, fecal transplants, prions, virophages, giant Mimi viruses, cervical cancer, and immunology.

One of the most interesting ideas new to immunology is found in the opener to Chapter 18: are worms our friends? Many autoimmune diseases such as Crohn's disease and irritable bowel disease are being treated by giving the patient 2,500 whipworm eggs every 2 or 3 weeks. They hatch, but can't develop as they are in the wrong host. But they induce a win—win symbiosis: They induce a dampening of the host's inflammatory immune response, meaning that they don't get killed (their win). The human host wins by not having a huge inflammatory immune response which would lead to an autoimmune disease. Our ancestors must have all had many kinds of worms with which they could have evolved symbioses. Maybe it's time to go back to "our old friends, the worms."

The rapid advances being made in microbiology make teaching about—and learning about—microorganisms challenging. Therefore, every effort has been made in the ninth edition of Microbiology: Principles and Explorations to ensure that the writing is simple, straightforward, and functional; that microbiological concepts and methodologies are clearly and thoroughly described;

and that the information presented is as accessible as possible to students. Students who enjoy a course are likely to retain far more of its content for a longer period of time than those who take the course like a dose of medicine. There is no reason for a text to be any less interesting than the subject it describes. So, in addition to a narrative that is direct and authoritative, students will find injections of humor, engaging stories, and personal reflections that I hope impart a sense of discovery and wonder and a bit of my passion for microbial life.

Because students find courses most interesting when they can relate topics to their everyday life or to career goals, I have emphasized the connection between microbiological knowledge and student experiences. One way that this connection is made is through the many boxed essays described previously. Another is through the use of factoids, post-it type notes that are tidbits of information relating to the running text and that add an extra dimension of flavor to the discussion at hand.

Over 20 milion deaths each year are due to infectious disease.

Post-it type notes give additional information in the margin.

DESIGN AND ILLUSTRATIONS

The ninth edition of Microbiology: Principles and Explorations has been completely redesigned with an eye toward increasing the readability, enhancing the presentation of illustrations and photographs, and making the pedagogical features more effective for use. The use of clear, attractive drawings and carefully chosen photographs can significantly contribute to the student's understanding of a scientific subject. Throughout, color has been used not just decoratively but for its pedagogic value. For example, every effort has been made to color similar molecules and structures the same way each time they appear, making them easier to recognize.

Illustrations have been carefully developed to amplify and enhance the narrative. The line art in this text is sometimes as simple as a flow diagram or just as often a

FIGURE 20.24 **Genital warts of the penis.** *(Biophoto Associates/Science Source)*

Should boys be vaccinated with Gardasil against HPV?

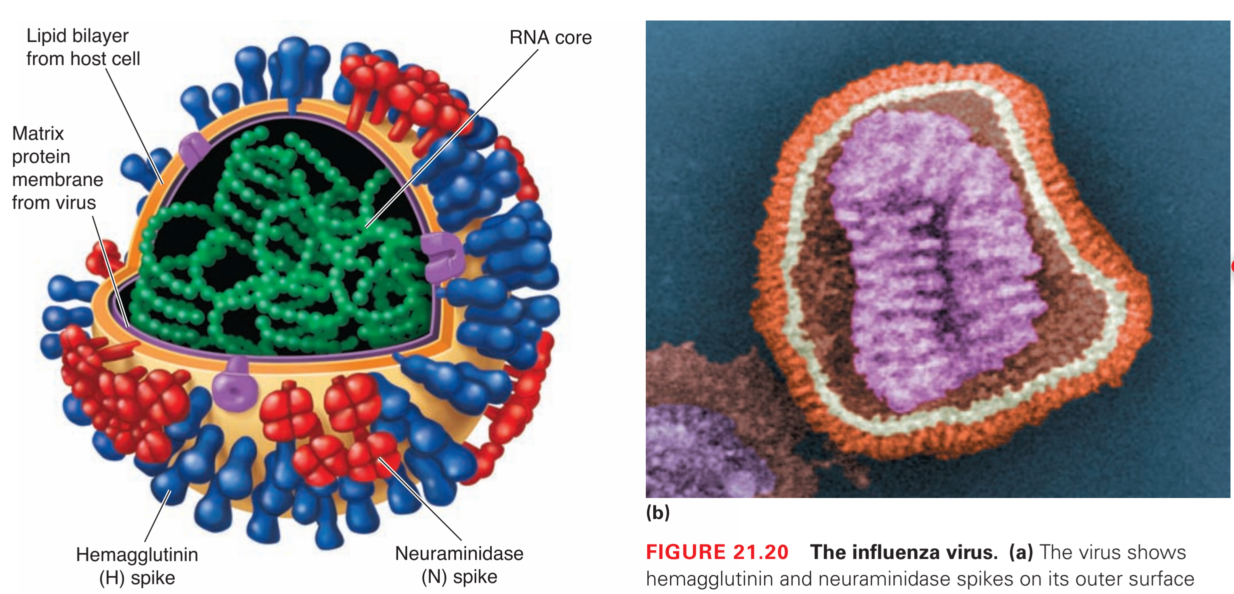
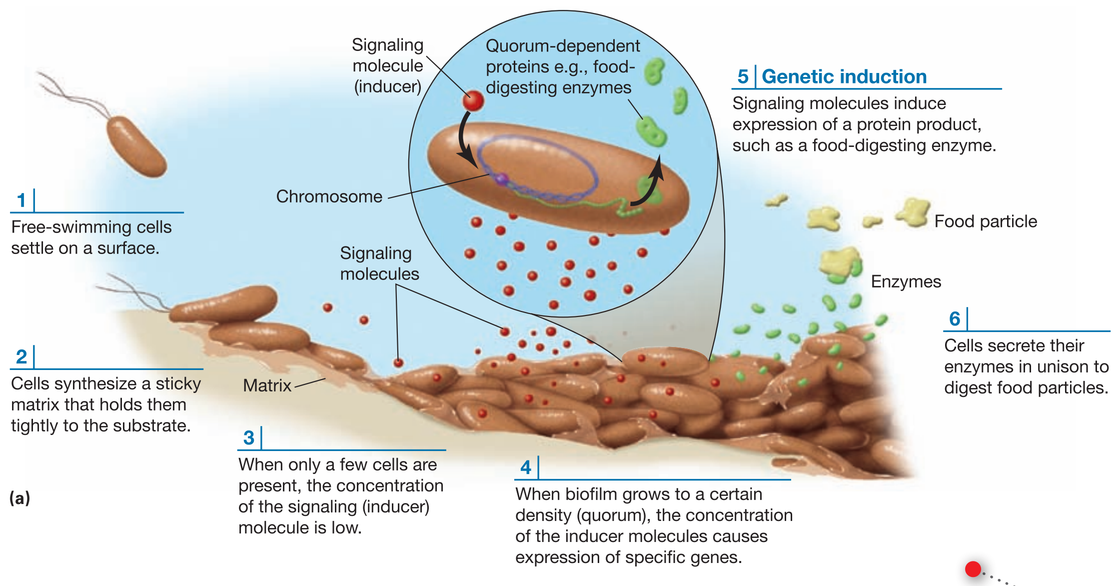


FIGURE 21.20 **The influenza virus.** **(a)** The virus shows hemagglutinin and neuraminidase spikes on its outer surface and an RNA core. **(b)** A colorized TEM of an influenza virion (magnification unknown). *(Science Source/Photo Researchers).*

Line drawings and photos complement each other.



New illustrations combine art and photos.

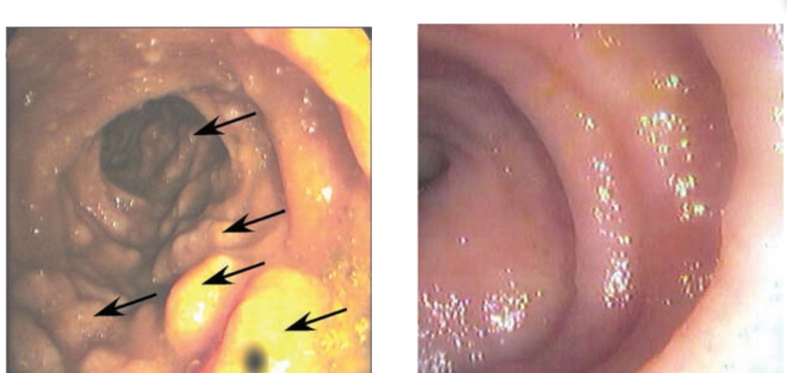
(b)

FIGURE 6.17 **(a) Quorum sensing. (b) Sibling warfare.** Bacteria in streaks from the same original colony will only grow away from each other, another example of microbial communication. *(Eshel Ben-Jacob)*

complex illustration of a structure drawn by some of the best medical illustrators working today.

Photographs also richly enhance the text. The diversity of the photo program encompasses numerous micrographs, photographs of clinical conditions, microbiologists at work, and some laboratory techniques and results. Often, you will find a photograph accompanied by a line drawing aiding in the understanding of an unfamiliar subject.

Paired photos illustrate the text discussion.



(a) (b)

Figure 18.24 Gastrointestinal tract endoscopy: before and a few weeks after HIV infection. **(a)** The interior lining of the gut of an uninfected person showing numerous lymph node patches (GALT). **(b)** The gut lining stripped of lymph node Peyer's patches in an HIV-infected person. *(Photographs from Brenchley et al., Journal of Experimental Medicine, 2004, Vol. 200, pp. 749–759 by copyright permission of The Rockefeller University Press.)*

The WileyPLUS Advantage

WileyPLUS is a research-based online environment for effective teaching and learning. *WileyPLUS* is packed with interactive study tools and resources, including the complete online textbook.

WileyPLUS includes many opportunities for self-assessment linked to the relevant portions of the text. Students can take control of their own learning and practice until they master the material.

The rich variety of Microbiology resources, including Animations, Videos, and Microbiology Roadmaps ensure that sudents know how to study effectively, remain engaged, and stay on track.

WileyPLUS with ORION

Different learning styles, different levels of proficiency, different levels of preparation—each of your students is unique. *WileyPLUS* empowers them to take advantage of their individual strengths. With ***WileyPLUS***, students receive timely access to resources that address their demonstrated needs, and get immediate feedback and remediation when needed.

WileyPLUS for Microbiology 9e is now supported by an adaptive learning module called **ORION**. Based on cognitive science, ORION provides students with a personal, adaptive learning experience so they can build proficiency in concepts and use their study time effectively. *WileyPLUS* with ORION helps students learn by learning about them.

***WileyPLUS* with ORION** is great as:

- An **adaptive pre-lecture tool** that assesses your students' conceptual knowledge so they come to class better prepared.
- A **personalized study** guide that helps students understand both strengths and areas where they need to invest more time, especially in preparation for quizzes and exams.

BEGIN

Unique to ORION, students **begin** by taking a quick **diagnostic** for any chapter. This will determine each student's baseline proficiency on each topic in the chapter. Students see their individual diagnostic report to help them decide what to do next with the help of ORION's rcommendations.

PRACTICE

For each topic, students can either Study or Practice. **Study** directs the student to the specific topic they choose in *WileyPLUS*, where they can read from the e-textbook, or use the variety of relevent resources available there.

Students can also practice, using questions and feedback powered by ORION's adaptive learning engine. Based on the results of their diagnostic and ongoing practice, ORION will present students with questions appropriate for their current level of understanding, and will continuously adapt to each student, helping them build their proficiency.

MAINTAIN

ORION includes a number of reports and ongoing recommendations for students to help them maintain their proficiency over time for each topic. Students can easily access ORION from multiple places within WileyPLUS. It does not require any additional registration, and there will not be any additional charge for students using this adaptive learning system.

3D Animations

To help explain "the most difficult topics in Microbiology to teach," a new set of animations by renowned 3D Visualization artist, Janet Iwasa, University of Utah, are included in this edition. An icon accompanying key illustrations and sections of the text directs students to these animations in *WileyPLUS*. A complete set of animations is listed here:

CHAPTER 2

Acids and Bases
Chemical Bonding
Polarity and Solubility
Types of Reactions and Equilibrium

CHAPTER 3

Staining Bacteria: The Gram Stain
Wavelength Analogy

CHAPTER 4

Endocytosis and Exocytosis
Endosymbiosis
Eukaryotic Cell Structure
Mitosis and Meiosis Compared
Molecular Movement
Osmosis
Peptidoglycan
Prokaryotic Cell Structure
3D Animation: What do bacteria look like?
3D Animation: What structures are found inside of bacteria?
3D Animation: What types of cell envelopes are found in bacteria?
3D Animation: What features are found on the surface of bacteria?

CHAPTER 5

Catabolism of Fats and Proteins
Cell Respiration
Competitive and Noncompetitive Inhibition of Enzymes
Functions of Enzymes and uses of ATP
Metabolism: The Sum of Catabolism and Anabolism
3D Animation: What becomes of electrons generated by glycolysis and the TCA cycle?

CHAPTER 6

Binary Fission
Budding
Endospore Formation
Enterotube
Streak Plate Method
3D Animation: How can we grow microorganisms in the laboratory?
3D Animation: What other roles do bacteriological media perform?
3D Animation: How can a pure culture of a microorganism be obtained?
3D Animation: Besides spread and pour plate counts, how else can we measure microbial populations?
3D Animation: How do bacteria communicate with their neighbors?

CHAPTER 7

End Product Inhibition
Enzyme Induction: the Lac Operon
Eukaryotic Genes Contain Introns
Mutations
Polymerase Chain Reaction
Protein Synthesis
Thymine Dimer Repair
3D Animation: How are genome sequences determined?
3D Animation: How is gene expression measured using genomics tools?
3D Animation: How do regulatory proteins control transcription?
3D Animation: How can mRNA be controlled?

CHAPTER 8

Gene Transfer: Transformation
Recombinant DNA
Transduction
3D Animation: How do bacteria acquire free DNA from their environment?
3D Animation: How do bacteria share their DNA directly with other bacteria?
3D Animation: How do viruses help transfer DNA into bacteria?
3D Animation: How do transposable elements influence DNA variation in bacteria?
3D Animation: How can molecular biology tools be used to improve microbial strains?
3D Animation: What roles do microbes play in agricultural biotechnology?

CHAPTER 9

DNA Hybridization
Five Kingdom System of Classification
Lateral Gene Transfer
Shrub of Life

CHAPTER 10

Replication of An Enveloped dsDNA Animal Virus
Replication of (+) sense RNA viruses: HIV
Replication of (+) sense RNA viruses: poliovirus
Replication of a Virulent Bacteriophage
Replication of Temperate Bacteriophage
3D Animation: How do viruses recognize and attach to host cells?
3D Animation: How do viruses enter host cells?
3D Animation: How do viruses replicate their genome?
3D Animation: How do replicated viruses exit their host cells?
3D Animation: How do viruses interact with host cells?
3D Animation: How do some viruses become highly virulent?

CHAPTER 13

Antivirals
Effects of Premature Termination of Antibiotic Treatment

CHAPTER 16

Inflammation
Non-Specific Disease Resistance

CHAPTER 17

Antibody Mediated Immunity
Cell Mediated Immunity
Introduction to Disease Resistance
Production of Monoclonal Antibodies
3D Animation: What is the Cell-Mediated Immune Response?
3D Animation: How does humoral immunity fight infection?

CHAPTER 18

Four Types of Hypersensitivity
Myasthenia Gravis

For Instructors

WileyPLUS empowers you with the tools and resources you need to make your teaching even more effective:

- You can customize your classroom presentation with a wealth of resources and functionality from PowerPoint slides to a database of rich visuals. You can even add your own materials to your *WileyPLUS* course.
- With *WileyPLUS* you can identify those students who are falling behind and intervene accordingly, without having to wait for them to come to office hours.
- *WileyPLUS* simplifies and automates such tasks as student performance assessment, making assignments, scoring student work, keeping grades, and more. For detailed information about what WileyPLUS offers for you and your students, please visit: http://www.wiley.com/college/sc/black

ALSO AVAILABLE

Laboratory Exercises in Microbiology, 4e (ISBN 9781118135259) Robert A. Pollack, Lorraine Findlay, Walter Mondschein, and R. Ronald Modesto is a publication that carefully corresponds to *Microbiology* 9e. This hands-on laboratory manual contains a variety of interactive activities and experiments that teach students the basic concepts of microbiology. It also covers methods that allow the safe movement or transfer of microbial cells from one type of growth environment to another, classification and identification of microbes, and microbial biochemistry.

ACKNOWLEDGMENTS

Thanks really must go to the many people who have helped this ninth edition become a reality. Critical team members include Bonnie Roth, Senior Acquisitions Editor; Joan Kalkut, Sponsoring Editor; Ellen Ford, Outside Development Editor; Elizabeth Swain, Senior Production Editor; Wendy Lai, Senior Designer; Clay Stone, Executive Marketing Manager; Mary Ann Price, Photo Researcher; and Chloe Moffett, Editorial Program Assistant;

Most importantly, I would like to thank the many reviewers who have taken the time to share their comments and suggestions for enhancing each edition of this text. Your input makes a considerable difference.

REVIEWERS

Kari Cargill, Montana State University
Margaret Das, Southern Connecticut State University
John Flaspohler, Concordia College
Thomas R. Gustad, North Dakota State University
Michael Harman, Lone Star College - North Harris
James C. Ivey, Lansing Community College
Mark D. Johnson, St. Joseph College
Melissa C. Liechty, Brevard Community College
Heather Seitz, Johnson County Community College
Sasha Showsh, University of Wisconsin - Eau Claire
Tanya Soule, Indiana University - Purdue University Fort Wayne

Reviewers and Focus Group Participants for Previous Editions

Ronald W. Alexander, Tompkins Cortland Community College
D.Andy Anderson, Utah State University
Richard Anderson, Modesto Community College
Rod Anderson, Ohio Northern University
Oswald G. Baca, University of New Mexico
John Baird, Rose State College
David L. Balkwill, Florida State University
Keith Bancroft, Southeastern Louisiana University
James M. Barbaree, Auburn University
Jeanne K. Barnett, University of Southern Indiana
Hazel Barton, Northern Kentucky University
Sally McLaughlin Bauer, Hudson Valley Community College
Rebekah Bell, University of Tennessee at Chattanooga
R. L. Bernstein, San Francisco State University
Gregory Bertoni, Columbus State Community College
David L. Berryhill, North Dakota State University
Margaret Beucher, University of Pittsburgh
Steven Blanke, University of Houston
Alexandra Blinkova, University of Texas
Richard D. Bliss, Yuba College
Kathleen A. Bobbitt, Wagner College
Katherine Boettcher, University of Maine
Clifford Bond, Montana State University
Susan Bornstein-Forst, Marian University
Edward A. Botan, New Hampshire Technical College

Benita Brink, Adams State College
Kathryn H. Brooks, Michigan State University
Burke L. Brown, University of South Alabama
Daniel Brown, Santa Fe Community College
Linda Brushlind, Oregon State University
Barry Chess, Pasadena Community College
Kotesward Chintalacharuvu, UCLA
Richard Coico, City University of New York Medical School
William H. Coleman, University of Hartford
Iris Cook, Westchester Community College
Thomas R. Corner, Michigan State University
Christina Costa, Mercy College
Don Dailey, Austin Peay State University
Judith K. Davis, Florida Community College at Jacksonville
Mark Davis, University of Evansville
Dan C. DeBorde, University of Montana
Sally DeGroot, St. Petersburg Junior College
Michael Dennis, Montana State University at Billings
Monica A. Devanas, Rutgers University
Von Dunn, Tarrant County Junior College
John G. Dziak, Community College of Allegheny County
Susan Elrod, California Polytechnic State University
Elizabeth Emmert, Salisbury University
Nwadiuto Esiobu, Florida Atlantic University
Mark Farinha, University of North Texas
David L.Filmer, Purdue University
Eugene Flaumenhaft, University of Akron
Pamela B.Fouche,Walters State Community College
Christine L.Frazier, Southeast Missouri State University
Denise Y.Friedman, Hudson Valley Community College
Ron Froehlich, Mt. Hood Community College
David E. Fulford, Edinboro University of Pennsylvania
Jason Furrer, University of Missouri
Sara K. Germain, Southwest Tennessee Community College
William R. Gibbons, South Dakota State University
Eric Gillock, Fort Hays State University
Krista Granieri, College of San Mateo
Mike Griffin, Angelo State University
Van H. Grosse, Columbus State University
Richard Hanke, Rose State College
Pamela L. Hanratty, Indiana University
Janet Hearing, State University of New York, Stony Brook
Ali Hekmati, Mott Community College
Anne Hemsley, Antelope Valley College
Donald Hicks, Los Angeles Community College
Julie Higgins, Arkansas State University
Lawrence W. Hinck, Arkansas State University
Elizabeth A. Hoffman, Ashland Community College
Clifford Houston, University of Texas
Dale R. Horeth, Tidewater Community College
Ronald E. Hurlbert, Washington State University
Michael Hyman, North Carolina State University
John J. Iandolo, Kansas State University
Elizabeth Ingram, Valencia Community College
Robert J. Janssen, University of Arizona
Thomas R. Jewell, University of Wisconsin—Eau Claire
Wallace L. Jones, De Kalb College
Rhonda Jost, Florida State College
Ralph Judd, University of Montana
Helmut Kae, University of Hawaii - Leeward Community College
Karen Kendall-Fite, Columbia State Community College
John W. Kimball, Harvard University
Karen Kirk, Lake Forest College
Timothy A. Kral, University of Arkansas
Helen Kreuzer, University of Utah
Michael Lawson, Montana Southern State College
Donald G. Lehman, Wright State University
Jeff Leid, Northern Arizona University
Harvey Liftin, Broward Community College
Roger Lightner, University of Arkansa, Fort Smith
Tammy Liles, Lexington Community College
Terri Lindsey, Tarrant County College
Cynthia Littlejohn, University of Southern Mississippi
Jeff Lodge, Rochester Institute of Technology
William Lorowitz, Weber State University
Melanie Lowder, University of North Carolina at Charlotte
Marty Lowe, Bergen Community College
Victor Madike, Community College of Baltimore County - Dundalk
Caleb Makukutu, Kingwood College
Stanley Maloy, San Diego State University
Anita Mandal, Edward Waters College
Alesandria Manrov, Tidewater Community College, Virginia Beach
Sergei Markov, Austin Peay State University
Judy D. Marsh, Emporia State University
Rosemarie Marshall, California State University, Los Angeles
John Martinko, Southern Illinois University
Anne Mason, Yavapai College
William C. Matthai, Tarrant County Junior College
Mary V. Mawn, Hudson Valley Community College
Robin Maxwell, University of North Carolina at Greensboro
Pam McLaughlin, Madisonville Community College
Robert McLean, Southwest Texas State University
Elizabeth McPherson, University of Tennessee
Karen Messley, Rock Valley College
Joe Mester, Northern Kentucky University
Chris H. Miller, Indiana University
Rajeev Misra, Arizona State University

Barry More, Florida Community College at Jacksonville
Timothy Nealon, St. Philip's College
Rebecca Nelson, Pulaski Technical College
Wales Nematollahi, Utah State University - Tooele
Russell Nordeen, University of Arkansa, Monticello
Russell A. Normand, Northeast Louisiana University
Christian C. Nwamba, Wayne State University
Douglas Oba, Brigham Young University—Hawaii
Roselie Ocamp-Friedmann, University of Florida
Cathy Oliver, Manatee Community College
Raymond B. Otero, Eastern Kentucky University
Curtis Pantle, Community College of Southern Nevada
C.O. Patterson, Texas A & M University
Kimberley Pearlstein, Adelphi University
Roberta Petriess, Witchita State University
Robin K. Pettit, State University of New York, Potsdam
Robert W. Phelps, San Diego Mesa College
Marcia Pierce, Eastern Kentucky University
George Pinchuck, Mississippi University for Women
Holly Pinkart, Central Washington University
Robert A. Pollack, Nassau Community College
Jeff Pommerville, Glendale Community College
Leodocia Pope, University of Texas at Austin
Madhura Pradhan, Ohio State University
Jennifer Punt, Haverford College
Ben Rains, Pulaski Technical College
Eric Raymond Paul, Texas Tech University
Clifford Renk, Florida Gulf Coast University
Jane Repko, Lansing Community College
Quentin Reuer, University of Alaska, Anchorage
Kathleen Richardson, Portland Community College
Robert C. Rickert, University of California, San Diego
Russell Robbins, Drury College
Karl J. Roberts, Prince George's Community College
Richard A. Robison, Brigham Young University
Meredith Rodgers, Wright State University
Rodney Rohde, Austin Community College
Dennis J. Russell, Seattle Pacific University
Frances Sailer, University of North Dakota
Gordon D. Schrank, St. Cloud State University
Lois Sealy, Valencia Community College
Alan J. Sexstone, West Virginia University
Deborah Simon-Eaton, Santa Fe Community College
K.T. Shanmugam, University of Florida
Victoria C. Sharpe, Blinn College
Pocahontas Shearin Jones, Halifax Community College
Jia Shi, De Anza College
Richard Shippee, Vincennes University
Brian R. Shmaefsky, Kingwood College
Sara Silverstone, State University of New York, Brockport
Robert E. Sjogren, University of Vermont
Ralph Smith, Colorado State University
D. Peter Snustad, University of Minnesota
Juliet Spencer, University of San Francisco
Larry Snyder, Michigan State University
Joseph M. Sobek, University of Southwestern Louisiana
J. Glenn Songer, University of Arizona
Jay Sperry, University of Rhode Island
Paula Steiert, Southwest Baptist University
Paul M. Steldt, St. Philips College
Bernice C. Stewart, Prince George's Community College
Gerald Stine, University of Florida
Larry Streans, Central Piedmont Community College
Kent R. Thomas, Wichita State University
Paul E.Thomas, Rutgers College of Pharmacy
Teresa Thomas, Southwestern College
Grace Thornhill, University of Wisconsin—River Falls
Jack Turner, University of Southern California—Spartanburg
James E. Urban, Kansas State University
Manuel Varella, Eastern New Mexico University
Delon Washo-Krupps, Arizona State University
Winfred E. Watkins, McLennan Community College
Valerie A. Watson, West Virginia University
John Whitlock, Hillsborough Community College
Phylis K.Williams, Sinclair Community College
George A. Wistreich, East Los Angeles College
Shawn Wright, Albuquerque Technical-Vocational Institute
Michael R. Yeaman, University of New Mexico
John Zak, Texas Tech University
Mark Zelman, Aurora University
Thomas E. Zettle, Illinois Central College

Comments and suggestions about the book are most welcome. You can contact me through my editors at John Wiley and Sons.

Jacquelyn Black and Laura Black
Arlington, Virginia

Brief Contents

Appendices A-E can be found at www.wiley.com/college/black and in *WileyPLUS*

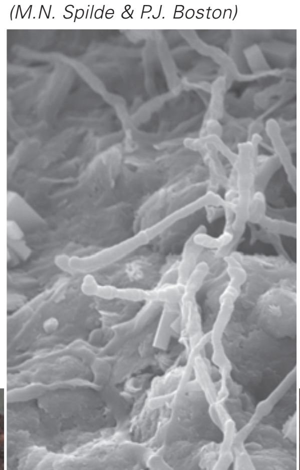
Contents

CHAPTER 1

Scope and History of Microbiology

You'll Die in 30 Minutes Here! What's a Microbiologist Doing Here?

(M.N. Spilde & P.J. Boston)



Come with geomicrobiologist Dr. Penny Boston, deep under the Chihuahuan Desert of Mexico, to a cave full of giant gypsum crystals weighting over 5 tons each. A pump has drained out the scalding hot water in which they were immersed for over 100 million years. The cave sits atop a chamber of volcanic magma which heats it to 50°C (120°F) and 99% humidity. Even with special suits, breathing apparatus and ice packs, a human can survive here for less than 30 minutes. But Penny Boston has found over 80 kinds of bacteria living inside fluid in the crystals. All never seen on earth before. She has done their DNA and they are unique. Each drop of fluid also holds over 200 million bacteriophages, a type of virus that eats bacteria! As the crystals grew, defects in their latticework of molecules left small holes which filled with the water bathing them—hot and full of microbes. Further growth closed these holes, preserving the bacteria and viruses alive in the fluid. Most of them are still alive! They are living fossils over a half million years old! They are not dormant. They have a superslow metabolism, extra food just kills them. Red colored bacteria growing on the 80–85 billion year old limestone walls of the cave are also alive.

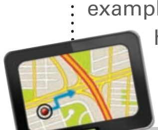
These microbes are living in what is called the "deep hot biosphere," like what much of the early earth was like.

They need no light, no organic matter; they eat the minerals they are entombed with. Are there similar conditions on other planets or their moons that could also have given rise to life? Europa, a moon of Jupiter, in covered with ice but has a 60-mile-deep ocean of liquid nitrogen, which sits on volcanic heat. It certainly is deep and hot—perhaps it is a "deep hot biosphere." Titan and Enceladus, moons of Saturn, also have such places. Most of the time that there has been life on Earth, it has been solely bacteria and viruses. Perhaps

Scientists(left) in ice-cooled suits explore Mexico's deadly hot Cave of Crystals.
(C. Oscar Necoechea - S/F [speleoresearch and film])

Microbiology Roadmap

Visit the companion website for the Microbiology Roadmap with practice questions, current examples, and other tools to help you study, review, and master the key concepts of the chapter.



we'll find more kinds of microbes elsewhere in the universe. Studying the ones found in the Crystal Cave may give us a better idea of what to look for.

More surprises lie ahead. Oh! The things we'll learn in this course—it's going to be a real adventure!

To read about more cave explorations by Dr. Penny Boston and Dr. Diana Northrup, see Chapter 25, p. 816.

Video related to this topic is available within *WileyPLUS*.

CHAPTER MAP

Follow the Chapter Map to help you pinpoint the core concepts in the chapter.

Almost one-half of children under the age of 10 died of infectious disease prior to the last century.

"It's just some 'bug' going around." You have heard that from others or said it yourself when you have been ill for a day or two. Indeed, the little unidentified illnesses we all have from time to time and attribute to a "bug" are probably caused by viruses, the tiniest of all *microbes*. Other groups of **microorganisms**—bacteria, fungi, protozoa, and some algae—also have disease-causing members. Before studying microbiology, therefore, we are likely to think of microbes as germs that cause disease. Health scientists are concerned with just such microbes and with treating and preventing the diseases they cause. Yet less than 1% of known microorganisms cause disease, so focusing our study of microbes exclusively on disease gives us too narrow a view of microbiology.

WHY STUDY MICROBIOLOGY?

Microbes in the Environment and Human Health

If you were to dust your desk and shake your dust cloth over the surface of a medium designed for growing microorganisms, after a day or so you would find a variety of organisms growing on that medium. If you were to cough onto such a medium or make fingerprints on it, you would later find a different assortment of microorganisms growing on the medium. When you have a sore throat and your physician orders a throat culture, a variety of organisms will be present in the culture—perhaps including the one that is causing your sore throat. Thus, microorganisms have a close association with humans. They are in us, on us, and nearly everywhere around us (**Figure 1.1**). One reason for studying microbiology is that *microorganisms are*

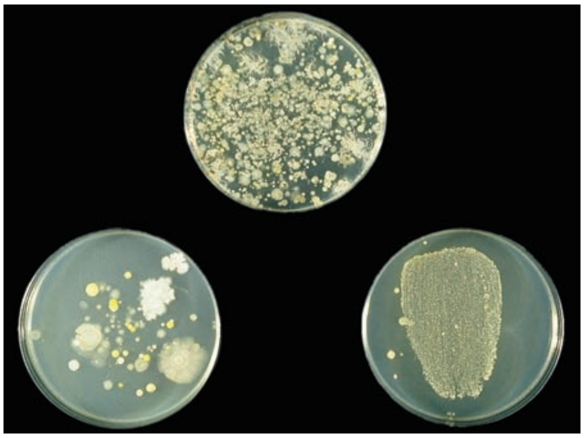


FIGURE 1.1 A simple experiment shows that microorganisms are almost everywhere in our environment. Soil was added to nutrient agar, a culture medium (dish on top); another dish with agar was exposed to air (bottom left); and a tongue print was made on an agar surface (bottom right). After 3 days of incubation under favorable conditions, abundant microbial growth is easily visible in all three dishes. *(Courtesy Jacquelyn G. Black)*

part of the human environment and are therefore important to human health.

Microorganisms are essential to the web of life in every environment. Many microorganisms in the ocean and in bodies of fresh water capture energy from sunlight and store it in molecules that other organisms use as food. Microorganisms decompose dead organisms, waste material from living organisms, and even some kinds of industrial wastes. They make nitrogen available to plants.

These are only a few of the many examples of how microorganisms interact with other organisms and help maintain the balance of nature. The vast majority of microorganisms are directly or indirectly beneficial, not only to other organisms, but also to humans. They form essential links in many food chains that produce plants and animals that humans eat. Aquatic microbes serve as food for small macroscopic animals that, in turn, serve as food for fish and shellfish that humans eat. Certain microorganisms live in the digestive tracts of grazing animals such as cattle and sheep and aid in their digestive processes. Without these microbes, cows could not digest grass, and horses would get no nourishment from hay. Humans occasionally eat microbes, such as some algae and fungi, directly. Mushrooms, for instance, are the macroscopic reproductive bodies of masses of microscopic fungi. Biochemical reactions carried out by microbes also are used by the food industry to make pickles, sauerkraut, yogurt and other dairy products, fructose used in soft drinks, and the artificial sweetener aspartame. Fermentation reactions in microorganisms are used in the brewing industry to make beer and wine, and in baking to leaven dough.

A bacterium may weigh approximately 0.00000000001 grams, yet collectively microbes constitute about 60% of the Earth's biomass.

One of the most significant benefits that microorganisms provide is their ability to synthesize *antibiotics*, substances derived from one microorganism that kill or restrict the growth of other microorganisms. Therefore, microorganisms can be used to cure diseases as well as cause them. Finally, microorganisms are the major tools of genetic engineering. Several products important to humans, such as interferon and growth hormones, can now be produced economically by microbes because of genetic engineering.

New organisms are being engineered to degrade oil spills, to remove toxic materials from soil, and to digest explosives that are too dangerous to handle. They will be major tools in cleaning up our environment. Other organisms will be designed to turn waste products into energy. Still other organisms will receive desirable genes from other types of organisms—for example, crop plants will be given bacterial genes that produce nitrogen-containing compounds needed for plant growth. The citizen of today, and even more so of tomorrow, must be scientifically literate, understanding many microbial products and processes.

Although only certain microbes cause disease, learning how such diseases are transmitted and how to diagnose, treat, and prevent them is of great importance in a health-science career. Such knowledge will help those of you who pursue such a career to care for patients and avoid becoming infected yourself.

CLOSE UP

We Are Not Alone

"We are outnumbered. The average human contains about 10 trillion cells. On that average human are about 10 times as many microorganisms, or 100 trillion microscopic beings. . . . As long as they stay in balance and where they belong, [they] do us no harm. . . . In fact, many of them provide some important services to us. [But] most are opportunists, who if given the opportunity of increasing growth or invading new territory, will cause infection."

—Robert J. Sullivan, 1989

Insight into Life Processes

Another reason for studying microbiology is that such study *provides insight into life processes in all life-forms.* Biologists in many different disciplines use ideas from microbiology and use the organisms themselves. Ecologists draw on principles of microbiology to understand how matter is decomposed and made available for continuous recycling. Biochemists use microbes to study metabolic pathways—sequences of chemical reactions in living organisms. Geneticists use microbes to study how hereditary information is transferred and how such information controls the structure and functions of organisms.

Microorganisms are especially useful in research for at least three reasons:

1. Compared to other organisms, microbes have relatively simple structures. It is easier to study most life processes in simple unicellular organisms than in complex multicellular ones.
2. Large numbers of microorganisms can be used in an experiment to obtain statistically reliable results at a reasonable cost. Growing a billion bacteria costs less than maintaining 10 rats. Experiments with large numbers of microorganisms give more reliable results than do those with small numbers of organisms with individual variations.
3. Because microorganisms reproduce very quickly, they are especially useful for studies involving the transfer of genetic information. Some bacteria can undergo three cell divisions in an hour, so the effects of gene transfer can quickly be followed through many generations.

By studying microbes, scientists have achieved remarkable success in understanding life processes and disease control. For example, within the last few decades, vaccines have nearly eradicated several dreaded childhood diseases—including measles, polio, German measles, mumps, and chickenpox. Smallpox, which once accounted for 1 out of every 10 deaths in Europe, has not been reported anywhere on the planet since 1978. Much has also been learned about genetic changes that lead to antibiotic resistance and about how to manipulate genetic information in bacteria. Much more remains to be learned. For example, how can vaccines be made available on a worldwide basis? How can the development of new antibiotics keep pace with genetic changes in microorganisms? How will increased world travel continue to affect the spread of infections? Will the continued encroachment of humans into virgin jungles result in new, emerging diseases? Can a vaccine or effective treatment for acquired immunodeficiency syndrome (AIDS) be developed? Therein lie some of the challenges for the next generation of biologists and health scientists.

We Are the Planet of Bacteria

The full extent and importance of bacteria to our planet is just now being revealed. Deep drilling projects have discovered bacteria living at depths that no one had believed possible. At first their presence was attributed to contaminated drilling materials from the surface. But now several careful studies have confirmed populations of bacteria truly native to depths such as 1.6 km in France, 4.2 km in Alaska, and 5.2 km in Sweden. It seems that no matter how far down we drill, we always find bacteria living there. But, as we approach the hot interior of the Earth, temperature increases with depth. The Alaskan bacteria were living at 110°C! Evidence has accumulated that there is a "**deep hot biosphere**," as named by American scientist Thomas Gold. This region of microbial life may extend down as far as 10 km below our "surface biosphere." At places along the border between these two biospheres, materials such as oil, hydrogen sulfide (H_2S), and methane (CH_4) are upwelling, carrying along with them bacteria from deep inside our planet. Scientists now speak of a "continuous subcrustal culture" of bacteria filling a deep hot zone lying beneath the entire Earth's surface. The mass of bacteria in the surface biosphere by far exceeds the total weight of all other living things. Add to this the weight of all the bacteria living inside the deep hot biosphere, and it is apparent that our Earth is truly "the planet of bacteria."

The cave shown in the photo at the beginning of this chapter is one of those places along the border between the two biospheres. In this book we will examine bacteria at other borderland sites (for example, black hot smoking vents located deep at the ocean bottom; cold seeps higher up in the ocean on the continental shelves; and boiling mud pots such as those at Yellowstone National Park in the United States and at the Kamchatka peninsula of Russia). And, of course, we will take a closer look at those fascinating caves shown at the beginning of this chapter.

SCOPE OF MICROBIOLOGY

Microbiology is the study of **microbes**, organisms so small that a microscope is needed to study them. We consider two dimensions of the scope of microbiology: (1) the variety of kinds of microbes, and (2) the kinds of work microbiologists do.

The Microbes

The major groups of organisms studied in microbiology are bacteria, algae, fungi, viruses, and protozoa (**Figure 1.2a–e**). All are widely distributed in nature. For example, a recent study of bee bread (a pollen-derived nutrient eaten by worker bees) showed it to contain 188 kinds of fungi and 29 kinds of bacteria. Most microbes consist of a single cell. (Cells are the basic units of structure and function in living things; they are discussed in ▶ Chapter 4.) Viruses, tiny acellular entities on the borderline between the living and the nonliving, behave like living organisms when they gain entry to cells. They, too, are studied in microbiology. Microbes range in size from small viruses 20 nm in diameter to large protozoans 5 mm or more in diameter. In other words, the largest microbes are as much as 250,000 times the size of the smallest ones! (Refer to ▶ Appendix A for a review of metric units.)

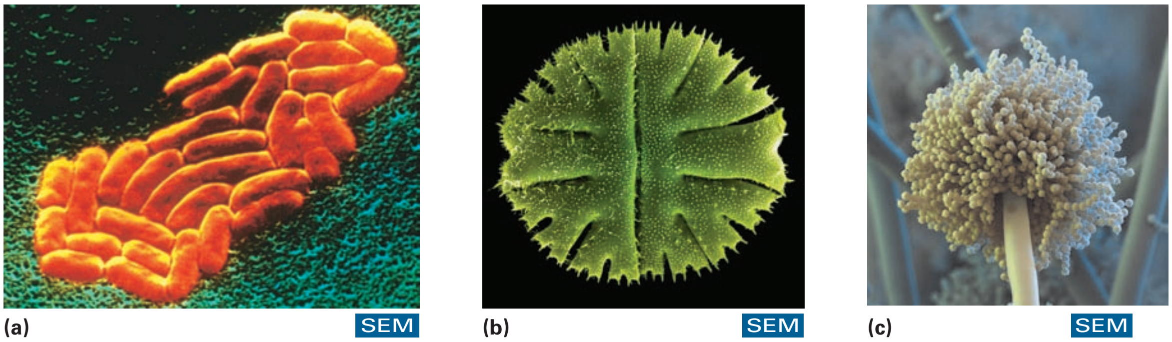
500 bacteria, each 1 μm (1/1000 of a millimeter) long, would fit end-to-end across the dot above the letter "i."

Bacteria

Among the great variety of microorganisms that have been identified, bacteria probably have been the most thoroughly studied. The majority of **bacteria** (singular: *bacterium*) are single-celled organisms with spherical, rod, or spiral shapes, but a few types form filaments. Most are so small they can be seen with a light microscope only under the highest magnification. Although bacteria are cellular, they do not have a cell nucleus, and they lack the membrane-enclosed intracellular structures found in most other cells. Many bacteria absorb nutrients from their environment, but some make their own nutrients by photosynthesis or other synthetic processes. Some are stationary, and others move about. Bacteria are widely distributed in nature, for example, in aquatic environments and in decaying matter. And some occasionally cause diseases.

Archaea

Very similar to bacteria are the group known as Archaea. They and the bacteria belong in the same Kingdom, called the Monera. A new category of classification, the **Domain**, has been erected as being higher than Kingdom. There are 3 Domains: Bacteria, Archaea, and Eukarya, which are discussed in ▶ Chapter 9, p. 251. Like Bacteria, the Archaea are single celled and do not have a nucleus. However, they are genetically and metabolically very



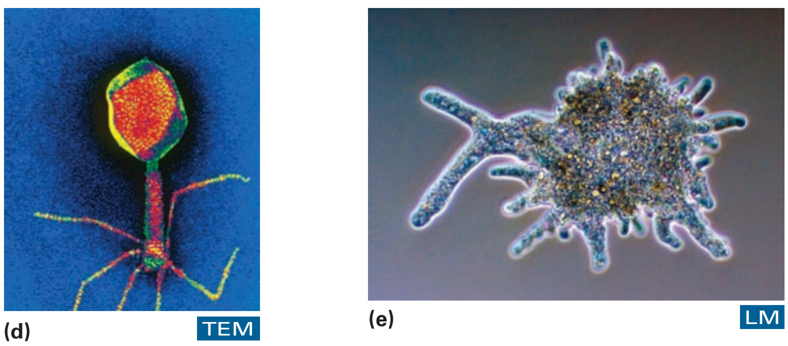


FIGURE 1.2 Typical microorganisms (enhanced with artificial coloring). **(a)** Several *Klebsiella pneumoniae* cells, a bacterium that can cause pneumonia in humans (5, 821X). *(CNRi/Science Source)* **(b)** *Micrasterius*, a green alga that lives in fresh water. *(SciencePR/Oxford Scientific/Getty)* **(c)** Spore bearing fruiting bodies of the fungus *Aspergillus niger*. *(Eye of Science/Science Source)* **(d)** Bacteriophages (viruses that infect bacteria; 35,500X). *(Eye of Science/Science Source)* **(e)** *Amoeba*, a protozoan (183X). *(Roland Birke/Photolibrary/Getty)* **(f)** Head of the tapeworm *Acanthrocirrus retrirostris* (189X). At the top of the head are hooks and suckers that the worm uses to attach to a host's intestinal tissues. *(Cath Ellis/Science Source)*

different. Many Archaea are extremophiles, preferring to live in environments having extreme temperatures, pH, salinities, and hydrostatic and osmotic pressures. Their lipids, cell walls, and flagella differ considerably from those of Bacteria. Archaea are not proven to cause disease in humans; in fact, many are very important in ruminant animal digestive tracts.

In contrast to bacteria, several groups of microorganisms consist of larger, more complex cells that have a cell nucleus. They include algae, fungi, and protozoa, all of which can easily be seen with a light microscope.

Algae

Many **algae** (al′je; singular: *alga*) are single-celled microscopic organisms, but some marine algae are large, relatively complex, multicellular organisms. Unlike bacteria, algae have a clearly defined cell nucleus and numerous membrane-enclosed intracellular structures. All algae photosynthesize their own food as plants do, and many can move about. Algae are widely distributed in both fresh water and oceans. Because they are so numerous and because they capture energy from sunlight in the food they make, algae are an important source of food for other organisms. Algae are of little medical importance; only one species, *Prototheca*, has been found to cause disease in humans. Having lost its chlorophyll, and therefore the ability to produce its own food, it now makes meals of humans.

Fungi

Like algae, many **fungi** (fun′ji; singular: *fungus*), such as yeasts and some molds, are single-celled microscopic organisms. Some, such as mushrooms, are multicellular, macroscopic organisms. Fungi also have a cell nucleus and intracellular structures. All fungi absorb ready-made nutrients from their environment. Some fungi form extensive networks of branching filaments, but the organisms themselves generally do not move. Fungi are widely distributed in water and soil as decomposers of dead organisms. Some are important in medicine either as agents of diseases such as ringworm and vaginal yeast infections or as sources of antibiotics.

Viruses

Viruses are acellular entities too small to be seen with a light microscope. They are composed of specific chemical substances—a nucleic acid and a few proteins (▶ Chapter 2). Indeed, some viruses can be crystallized and stored in a container on a shelf for years, but they retain the ability to invade cells. Viruses replicate themselves and display other properties of living organisms only when they have invaded cells. Many viruses can invade human cells and cause disease. Even smaller acellular agents of disease are **viroids** (nucleic acid without a protein coating), and **prions** (protein without any nucleic acid). Viroids have been shown to cause various plant diseases, whereas prions cause mad cow disease and related disorders. New information about prions has just exploded in the last 2 years. We will explore this in ▶ Chapter 10.

Protozoa

Protozoa (pro-to-zo′ah; singular: *protozoan*) also are single-celled, microscopic organisms with at least one nucleus and numerous intracellular structures. A few species of amoebae are large enough to be seen with the naked eye, but we can study their structure only with a microscope. Many protozoa obtain food by engulfing or ingesting smaller microorganisms. Most protozoa can move, but a few, especially those that cause human disease, cannot. Protozoa are found in a variety of water and soil environments, as well as in animals such as malaria-carrying mosquitoes.

Helminths and Arthropods

In addition to organisms properly in the domain of microbiology, in this text we consider some macroscopic *helminths* (worms) (**Figure 1.2f**) and *arthropods* (insects and similar organisms). The helminths have microscopic stages in their life cycles that can cause disease, and the arthropods can transmit these stages, as well as other disease-causing microbes.

Taxonomy

We will learn more about the classification of microorganisms in ▶ Chapter 9. For now it is important to know only that cellular organisms are referred to by two names: their *genus* and *species* names. For example, a bacterial species commonly found in the human gut is called *Escherichia coli*, and a protozoan species that can cause severe diarrhea is called *Giardia intestinalis.* The naming of viruses is less precise. Some viruses, such as herpesviruses, are named for the group to which they belong. Others, such as polioviruses, are named for the disease they cause.

Disease-causing organisms and the diseases they cause in humans are discussed in detail in ▶ Chapters 19–24. Hundreds of infectious diseases are known to medical science. Some of the most important—those diseases that physicians should report to the U.S. Centers for Disease Control and Prevention (CDC)—are listed in **Table 1.1**. The CDC is a federal agency that collects data about diseases and about developing ways to control them.

The Microbiologists

Microbiologists study many kinds of problems that involve microbes. Some study microbes mainly to find out more about a particular type of organism—the life stages of a particular fungus, for example. Other microbiologists are interested in a particular kind of function, such as the metabolism of a certain sugar or the action of a specific gene. Still others focus directly on practical problems, such as how to purify or synthesize a new antibiotic or how to make a vaccine against a particular disease. Quite often the findings from one project are useful in another, as when agricultural scientists use information from microbiologists to control pests and improve crop yields, or when environmentalists attempt to maintain natural food chains and prevent damage to the environment. Some fields of microbiology are described in **Table 1.2**.

Microbiologists work in a variety of settings (**Figure 1.3**). Some work in universities, where they are likely to teach, do research, and train students to do research. Microbiologists in both university and commercial laboratories are helping to develop the microorganisms used in genetic engineering. Some law firms are hiring microbiologists to help with the complexities of patenting new genetically engineered organisms. These organisms can be used in such important ways as cleaning up the environment (*bioremediation*), controlling insect pests, improving foods, and fighting disease. Many microbiologists work in health-related positions. Some work in clinical laboratories, performing tests to diagnose diseases or determining which antibiotics will cure a particular disease. A few microbiologists develop new clinical tests. Others work in industrial laboratories to develop or manufacture antibiotics, vaccines, or similar biological products. Still others, concerned with controlling the spread of infections and related public health matters, work in hospitals or government labs. Please go to the website for this chapter, http://www.wiley.com/college/black, to read an interview with a keeper and a veterinarian from the Smithsonian's National Zoo in Washington, D.C. See how important microbiology is there!

From the point of view of health scientists, today's research is the source of tomorrow's new technologies. Research in *immunology* is greatly increasing our knowledge of how microbes trigger host responses and how the microbes escape these responses. It also is contributing to the development of new vaccines and to the treatment of immunologic disorders. Research in *virology* is improving our understanding of how viruses cause infections and how they are involved in cancer. Research in *chemotherapy* is increasing the number of drugs available to treat infections and is also improving our knowledge of how these drugs work. Finally, research in *genetics* is providing new information about the transfer of genetic information and, especially, about how genetic information acts at the molecular level.

STOP and CHECK

1. List three reasons to study microbiology.
2. What is the difference between microbiology and bacteriology?
3. What is the difference between etiology and epidemiology?
4. List five bacterial diseases and five viral diseases.

TABLE 1.1 Nationally Notifiable Infectious Conditions by Cause* (U.S. 2014, CDC)

Bacterial Diseases

Anthrax
Botulism
  Foodborne; infant; other (wound and unspecified)
Brucellosis
Chancroid
Chlamydia trachomatis infections
Cholera
Dengue
  Dengue fever; dengue hemorrhagic fever; dengue shock syndrome
Diphtheria
Ehrlichiosis/Anaplasmosis
  Ehrlichia chaffeensis; *Ehrlichia euringii*; *Anaplasma phagocytophilum*; undetermined
Gonorrhea
Haemophilus influenzae (invasive disease)
Hansen's disease (leprosy)
Hemolytic uremic syndrome, post-diarrheal
Legionellosis
Leptospirosis
Listeriosis
Lyme disease
Meningococcal disease
Pertussis (whooping cough)
Plague
Psittacosis
Q Fever
  Acute; chronic
Salmonellosis
Shiga toxin-producing *Escherichia coli* (STEC)
Shigellosis
Spotted Fever Rickettsiosis
Streptococcal toxic-shock syndrome
Streptococcus pneumoniae (invasive disease)
Syphilis
  Primary; secondary; latent; early latent; late latent; latent, unknown duration; neurosyphilis; late, non-neurological; stillbirth; congenital
Tetanus
Toxic-shock syndrome (other than *Streptococcus*)
Tuberculosis
Tularemia
Typhoid fever
Vancomycin-intermediate *Staphylococcus aureus* (VISA)
Vancomycin-resistant *Staphylococcus aureus* (VRSA)
Vibriosis

Viral Diseases

AIDS has been reclassified as HIV stage III
Arboviral neuroinvasive and nonneuroinvasive diseases
  California serogroup virus disease
  Eastern equine encephalitis virus disease
  Powassan virus disease
  St. Louis encephalitis virus disease
  West Nile virus disease
  Western equine encephalitis virus disease
Hantavirus pulmonary syndrome
Hepatitis
  A, acute; B, acute; B, chronic; B virus, perinatal infection; C, acute; C, chronic
HIV infection
  AIDS has been reclassified as HIV stage III
  HIV infection, adult/adolescent (age >= 13 years)
  HIV infection, child (age >= 18 months and <13 years)
  HIV infection, pediatric (age <18 months)
Influenza-associated pediatric mortality
Measles
Mumps
Novel influenza A virus infections, e.g., H1N1
Poliomyelitis, paralytic
Poliomyelitis infection, nonparalytic
Rabies (animal, human)
Rubella
Rubella, congenital syndrome
Severe Acute Respiratory Syndrome-associated Coronavirus (SARS-CoV) disease
Smallpox
Varicella morbidity (chickenpox, shingles)
Varicella (deaths only)
Viral Hemorrhagic Fever due to:
  Ebola virus; Marburg virus; Arenavirus; Crimean-Congo Hemorrhagic Fever virus; Lassa virus; lujo virus; New World arenaviruses (Gunarito, Machupo, Junin, and Sabia viruses)
Yellow Fever

Algal Diseases

None

Fungal Diseases

Coccidioidomycosis

Protozoan Disease

Babesiosis
Cryptosporidiosis
Cyclosporiasis
Giardiasis
Malaria

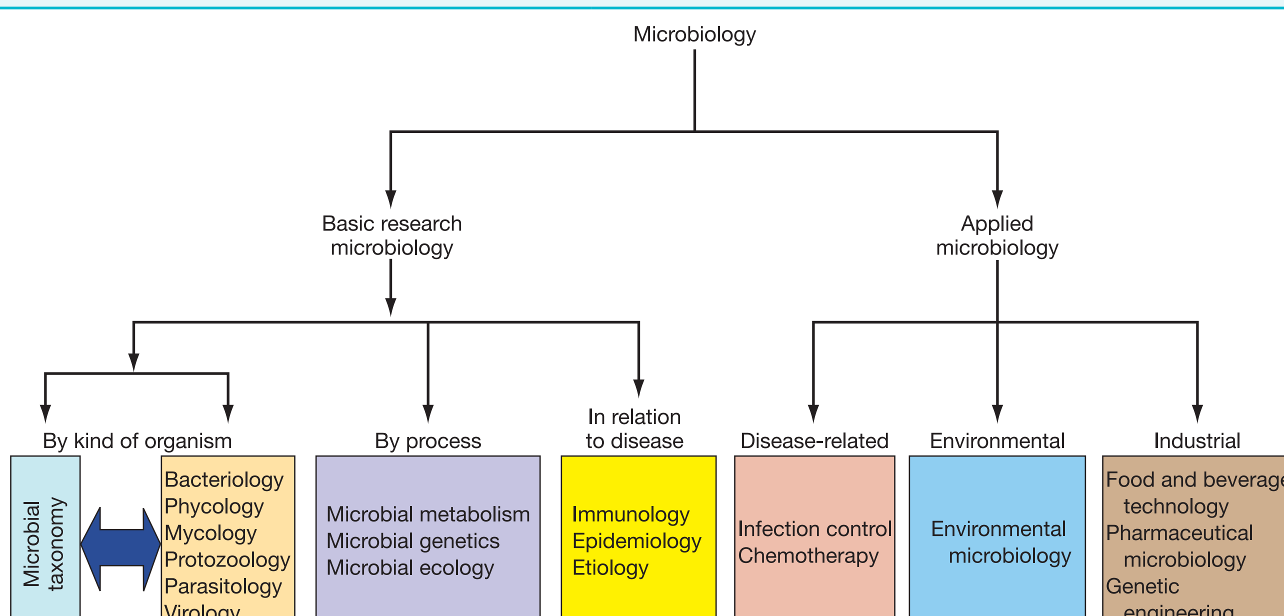
Helminth Disease

Trichinosis

*Infectious disease reporting varies by state. This table lists most of the diseases commonly reported to the U.S. Centers for Disease Control and Prevention (CDC) as of 2014.

TABLE 1.2 Fields of Microbiology 1

Field (Pronunciation)	Examples of What Is Studied
Microbial taxonomy	Classification of microorganisms
Fields According to Organisms Studied	
Bacteriology (bak″ter-e-ol′o-je)	Bacteria
Phycology (fi-kol′o-je)	Algae (*phyco*, "seaweed")
Mycology (mi-kol′o-je)	Fungi (*myco*, "a fungus")
Protozoology (pro″to-zo-ol′o-je)	Protozoa (*proto*, "first"; *zoo*, "animal")
Parasitology (par″a-si-tol′o-je)	Parasites
Virology (vi-rol′o-je)	Viruses
Fields According to Processes or Functions Studied	
Microbial metabolism	Chemical reactions that occur in microbes
Microbial genetics	Transmission and action of genetic information in microorganisms
Microbial ecology	Relationships of microbes with each other and with the environment
Health-Related Fields	
Immunology (im″u-nol′o-je)	How host organisms defend themselves against microbial infection
Epidemiology (epi-i-de-me-ol′o-je)	Frequency and distribution of diseases
Etiology (e-te-ol′-o-je)	Causes of disease
Infection control	How to control the spread of nosocomial (nos-o-ko′me-al), or hospital-acquired, infections
Chemotherapy	The development and use of chemical substances to treat diseases
Fields According to Applications of Knowledge	
Food and beverage technology	How to protect humans from disease organisms in fresh and preserved foods
Environmental microbiology	How to maintain safe drinking water, dispose of wastes, and control environmental pollution
Industrial microbiology	How to apply knowledge of microorganisms to the manufacture of fermented foods and other products of microorganisms
Pharmaceutical microbiology	How to manufacture antibiotics, vaccines, and other health products
Genetic engineering	How to use microorganisms to synthesize products useful to humans



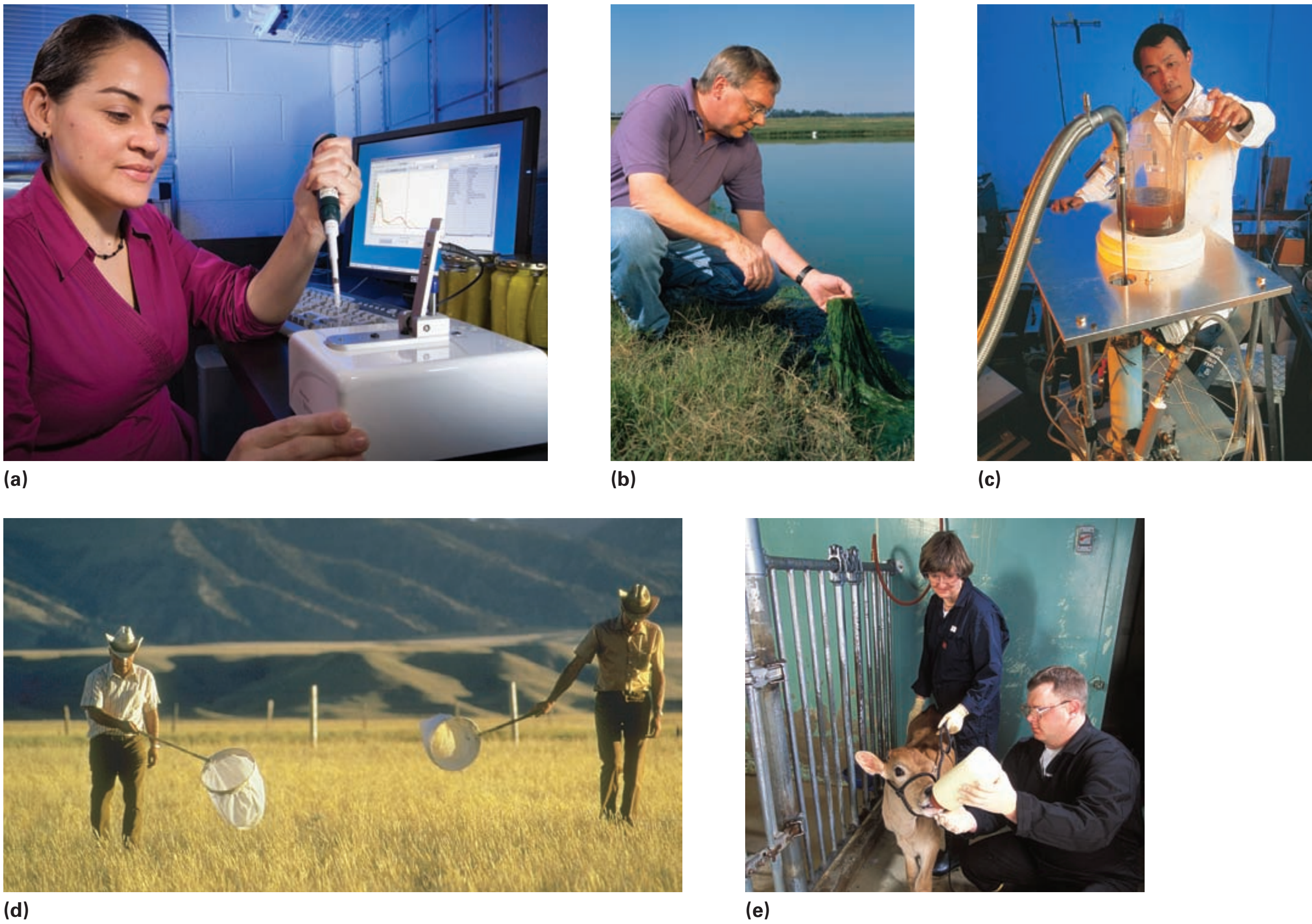


FIGURE 1.3 Microbiology is used in diverse careers. These careers include such activities as **(a)** food microbiologist examines cucumber brine *(Peggy Greb/Courtesy USDA)*; **(b)** algae being examined by agricultural microbiologist *(Peggy Greb/Courtesy USDA)*; **(c)** using bacteria to decontaminate toxic wastes *(David Parker/Science Source)*; **(d)** using beating nets to survey for ticks that can spread disease to livestock and humans *(Courtesy United States Department of Agriculture)*; **(e)** veterinary microbiologists vaccinate a calf orally. *(Stephen Ausmus/Courtesy USDA)*

HISTORICAL ROOTS

Many of the ancient Mosaic laws found in the Bible about basic sanitation have been used through the centuries and still contribute to our practices of preventive medicine. In Deuteronomy, Chapter 13, Moses instructed the soldiers to carry spades and bury solid waste matter. The Bible also refers to leprosy and to the isolation of lepers. Although in those days the term *leprosy* probably included other infectious and noninfectious diseases, isolation did limit the spread of the infectious diseases.

The Greeks anticipated microbiology, as they did so many things. The Greek physician Hippocrates, who lived around 400 B.C., set forth ethical standards for the practice of medicine that are still in use today. Hippocrates was wise in human relations and also a shrewd observer. He associated particular signs and symptoms with certain illnesses and realized that diseases could be transmitted from one person to another by clothing or other objects. At about the same time, the Greek historian Thucydides observed that people who had recovered from the plague could take care of plague victims without danger of getting the disease again.

The Romans also contributed to microbiology, as early as the first century B.C. The scholar and writer Varro proposed that tiny invisible animals entered the body through the mouth and nose to cause disease. Lucretius, a philosophical poet, cited "seeds" of disease in his *De Rerum Natura (On the Nature of Things)*.

Bubonic plague, also called the Black Death, appeared in the Mediterranean region around 542 A.D., where it reached epidemic proportions and killed millions. In 1347 the plague invaded Europe along the caravan routes and sea lanes from central Asia, affecting Italy first, then France, England, and finally northern Europe. Although no accurate records were kept at that time, it is estimated that tens of millions of people in Europe died during this and successive waves of plague over the next 300 years. The Black