

SIXTH EDITION

Microbiology

An Evolving Science

Joan L. Slonczewski

Kenyon College

John W. Foster

University of South Alabama

Erik R. Zinser

University of Tennessee, Knoxville

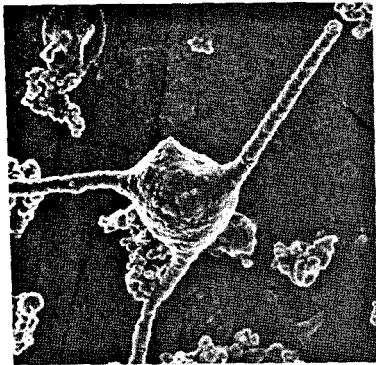


W. W. NORTON & COMPANY

Celebrating a Century of Independent Publishing

The  icon refers to content in the Norton Illumine Ebook.

eAppendix Contents xvi
 Preface xvii
 About the Authors xxxiv



PART 1

The Microbial Cell

CHAPTER 1

Microbial Life: Origin and Discovery..... 1

- 1.1** From Germ to Genome: What Is a Microbe? 2
- 1.2** Microbes Shape Human History 7
- 1.3** Medical Microbiology 15
- Special Topic 1** An mRNA Vaccine for COVID-19 20
- 1.4** Environment and Ecology 23
- 1.5** The Microbial Family Tree 28
- 1.6** Cell Biology and the DNA Revolution 31

eResearch Activity 1 Do Bacteria Make Neurotransmitters for the Human Brain? 

CHAPTER 2

Observing the Microbial Cell.....39

- 2.1** Observing Microbes 40
- 2.2** Optics and Properties of Light 45
- 2.3** Bright-Field Microscopy and Phase-Contrast Microscopy 48
- 2.4** Fixation and Staining for Bright-Field Microscopy 54
- 2.5** Fluorescence Microscopy, FISH, and Chemical Imaging Microscopy 57
- Special Topic 2** Biogeography of a Gut Pathogen 64
- 2.6** Electron Microscopy, Scanning Probe Microscopy, and X-Ray Crystallography 67
- eResearch Activity 2** How Do Bacteria Make a Magnet Chain? 

CHAPTER 3

Cell Structure and Function79

- 3.1 The Bacterial Cell: An Overview 80
- 3.2 Membrane Molecules and Transport 87
- 3.3 The Envelope and Cytoskeleton 92
- 3.4 Bacterial Cell Division 103
- 3.5 Cell Asymmetry, Membrane Vesicles, and Extensions 108
- Special Topic 3** Bacteria Reach Out with Pearling Tubes and Nanopods 114
- 3.6 Specialized Structures 114
- eResearch Activity 3** How Do a Hundred Cells Divide at Once? 

CHAPTER 4

Bacterial Culture, Growth, and Development.....123

- 4.1 Microbial Nutrition 124
- 4.2 Nutrient Uptake 129
- 4.3 Culturing and Counting Bacteria 135
- Special Topic 4** Factors from a Marine Sponge That Resuscitate “Microbial Dark Matter” 142
- 4.4 The Growth Cycle 146
- 4.5 Biofilms 153
- 4.6 Cell Differentiation 158
- eResearch Activity 4** Can Bacteria Unite to Defeat Predators? 

CHAPTER 5

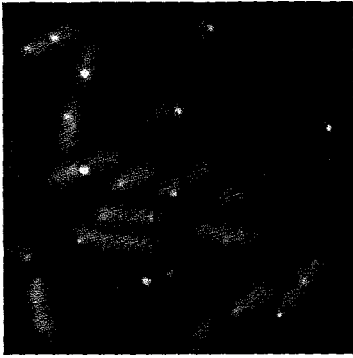
Environmental Influences and Control of Microbial Growth..... 165

- 5.1 Extremophiles and the Constraints of Temperature and Pressure 166
- 5.2 Osmolarity and Halophiles 173
- 5.3 Hydronium (pH) and Hydroxide Ion Concentrations 175
- 5.4 Oxygen 179
- 5.5 Starvation and Eutrophication 183
- 5.6 Physical, Chemical, and Biological Control of Microbes 186
- Special Topic 5** Phage Plus Antibiotics: A One-Two Punch against Bacterial Infections? 196
- eResearch Activity 5** Can Microbes Survive Trapped for 100 Million Years beneath a Seabed? 

CHAPTER 6

Viruses.....201

- 6.1 Viruses in Ecosystems 202
- 6.2 Virus Structure 210
- 6.3 Viral Genomes and Classification 216
- 6.4 Bacteriophages: The Gut Virome 222
- 6.5 Coronavirus SARS-CoV-2 and Other Viral Pathogens 229
- Special Topic 6** Found in Ferrets: Air Currents Carry SARS-CoV-2 232
- 6.6 Culturing Viruses 242
- eResearch Activity 6** Muddy and ZoeJ: Can Phages Discovered by Undergraduates Save a Patient’s Life? 



PART 2

Genes and Genomes

CHAPTER 7

Genomes and Chromosomes..... 249

- 7.1 DNA: The Genetic Material 250
- 7.2 Genome Organization 250
 - Special Topic 7** DNA as Digital Storage 256
- 7.3 DNA Replication 260
- 7.4 Plasmids and Secondary Chromosomes 270
- 7.5 Eukaryotic and Archaeal Chromosomes 275
- 7.6 Microbiomes and Metagenomes 277

eResearch Activity 7 Can Single-Cell Genomics Reveal Prebiotic Consumers of the Gut Microbiome? 

CHAPTER 8

Transcription, Translation, and Protein Processing..... 287

- 8.1 From DNA to RNA to Protein 288
- 8.2 Transcription of DNA to RNA 289
- 8.3 Translation of RNA to Protein 298
 - Special Topic 8** Rewriting the Genetic Code to Arrest Viral Infection 312
- 8.4 Protein Modification, Folding, and Degradation 314
- 8.5 Secretion: Protein Traffic Control 318

eResearch Activity 8 How Do Cells of the Same Species Recognize Each Other for DNA Exchange? 

CHAPTER 9

Genetic Change and Genome Evolution..... 327

- 9.1 Mutations 328
- 9.2 DNA Repair 334
- 9.3 Gene Transfer Mechanisms 340
- 9.4 Mobile Genetic Elements 350
- 9.5 Genome Evolution 355
 - Special Topic 9** Gut Microbiome Caught in the Act of Gene Transfer 362

eResearch Activity 9 How Do Mobile Genomic Islands Exploit Incoming Plasmids for Their Ticket to New Hosts? 

CHAPTER 10

Molecular Regulation 369

10.1 Transcription Repressors and Activators 370

10.2 Alternative Sigma Factors and Anti-Sigma Factors 382

10.3 Regulation by RNA 384

10.4 Second Messengers 392

10.5 Clocks, Thermometers, and Switches 400

Special Topic 10 Inteins, Exteins, and “Spliced-Up” Regulation 402

eResearch Activity 10 How Do Colonizing Symbiotic Bacteria Tell Their Hosts to Shut the Door Behind Them? 

CHAPTER 11

Viral Molecular Biology 411

11.1 Phage Lambda: Enteric Bacteriophage 412

11.2 Influenza Virus: (–) strand RNA Virus 421

Special Topic 11 Designing a Pandemic Flu 428

11.3 Human Immunodeficiency Virus (HIV): Retrovirus 432

11.4 Endogenous Retroviruses and Lentiviral Gene Therapy 443

11.5 Herpes Simplex Virus: DNA Virus 448

eResearch Activity 11 Could a Lentiviral Vector with CRISPR Cure Herpes? 

CHAPTER 12

Molecular Complexity and Synthetic Biology 457

12.1 Chemotaxis: Movement with a Destination 458

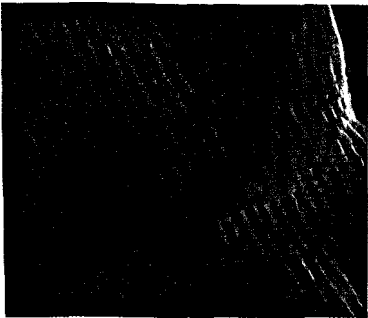
12.2 Biofilm Formation by *Pseudomonas aeruginosa* 463

12.3 CRISPR and Other Antiphage Defenses 469

12.4 Synthetic Biology: Biology by Design 481

Special Topic 12 Constructing the Smallest Genome for Cellular Life 484

eResearch Activity 12 Can Phage Jam a Host’s Communications to Block Antiphage Defense? 



PART 3

Metabolism and Biochemistry

CHAPTER 13
Energetics and Catabolism..... 493

13.1 Energy for Life 494

13.2 Energy Carriers and Electron Transfer 501

13.3 Catabolism: The Microbial Buffet 509

13.4 Glucose Fermentation and Respiration 514

13.5 Our Gut Microbiome: Friends with Benefits 529

Special Topic 13 Gut Bacteria Guide Host Behavior 530

13.6 Aromatic Catabolism and Syntrophy 534

eResearch Activity 13 Can *Escherichia coli* with a Rat Enzyme Convert Used Plastic Bottles to Vanillin? 

CHAPTER 14
Electron Flow in Organotrophy, Lithotrophy, and Phototrophy..... 543

14.1 Electron Transport Systems and the Proton Motive Force 544

14.2 The Respiratory ETS and ATP Synthase 555

14.3 Anaerobic Respiration 562

14.4 Nanowires, Electron Shuttles, and Fuel Cells 564

14.5 Lithotrophy and Methanogenesis 569

Special Topic 14 Bacteria with “Locs” Rule the Bay 570

14.6 Phototrophy 578

eResearch Activity 14 Can Silver Extensions Amplify Bacterial Electricity? 

CHAPTER 15
Biosynthesis 591

15.1 Overview of Biosynthesis 592

15.2 CO₂ Fixation: The Calvin Cycle and Other Pathways 596

Special Topic 15 Sunlight Makes Industrial Chemicals 604

15.3 Fatty Acids and Antibiotics 607

15.4 Nitrogen Fixation and Regulation 614

15.5 Amino Acids and Nucleobases 619

eResearch Activity 15 How Does Coculture Reveal a New Antibiotic from Sea Squirt Bacteria? 

CHAPTER 16

Food and Industrial Microbiology.....629

16.1 Microbial Foods 630

16.2 Acid-Fermented and Alkali-Fermented Foods 635

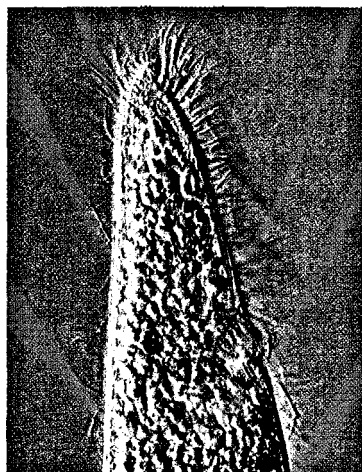
16.3 Ethanolic Fermentation: Bread and Wine 642

16.4 Food Spoilage and Preservation 646

16.5 Industrial Microbiology 656

Special Topic 16 Microbial Vitamins for Sale 658

16.6 Vaccines and Gene Therapy Vectors 665

eResearch Activity 16 How Did Microbial Enzymes Make the First COVID-19 Drug? 

PART 4

Microbial Diversity and Ecology

Microbial Diversity and Ecology

CHAPTER 17

Origins and Evolution.....673

17.1 Origins of Life 674

17.2 Forming the First Cells 683

17.3 Evolution: Phylogeny and Gene Transfer 686

17.4 Natural Selection and Adaptation 695

Special Topic 17 A Giant Petri Dish and the Race to Drug Resistance 696

17.5 Microbial Species and Taxonomy 705

17.6 Symbiosis and the Origin of Mitochondria and Chloroplasts 709

eResearch Activity 17 Does a Food Preservative Select for Stress-Induced Mutations? 

CHAPTER 18

Bacterial Diversity.....715

18.1 Bacterial Diversity at a Glance 716

18.2 Cyanobacteria: Oxygenic Phototrophs 723

18.3 Firmicutes, Mycoplasma, and Actinobacteria 728

Special Topic 18 Gut Bacterial Hairballs 732

18.4 Proteobacteria: From Photoheterotrophs to Lithotrophs 741

18.5 Spirochetes, Acidobacteria, Bacteroidetes, and Chlorobi 755

18.6 Planctomycetes, Verrucomicrobia, and Chlamydiae 758

eResearch Activity 18 Do Fecal Firmicutes Rewrite the Genetic Code? 

CHAPTER 19

Archaeal Diversity 763

- 19.1** Archaeal Diversity at a Glance 764
- 19.2** TACK Hyperthermophiles Eat Sulfur 772
- 19.3** Thaumarchaeota: Ammonia Oxidizers and Animal Symbionts 779
 - Special Topic 19** Ammonia-Oxidizing Archaea Keep Your Fish Healthy 782
- 19.4** Euryarchaeota: Methanogens from Gut to Globe 784
- 19.5** Haloarchaea and Other Euryarchaeotes: Underground and Under Ocean 791
- 19.6** DPANN Symbionts, Altitharchaeales, and Asgard: Branch to Eukaryotes 797
 - eResearch Activity 19** Can an Archaeal Fuel Cell Make Electric Current in Boiling Water? 

CHAPTER 20

Eukaryotic Diversity 803

- 20.1** Phylogeny of Eukaryotes 804
- 20.2** Fungi 812
 - Special Topic 20** Yeast: A Single-Celled Human Brain 816
- 20.3** Amoebozoa: Amebas and Slime Molds 824
- 20.4** Algae 828
- 20.5** Alveolates: Ciliates, Dinoflagellates, and Apicomplexans 835
- 20.6** Parasitic Protozoa and Microscopic Animals 842
 - eResearch Activity 20** Can Coral Endosymbiotic Algae Adapt to Rising Heat? 

CHAPTER 21

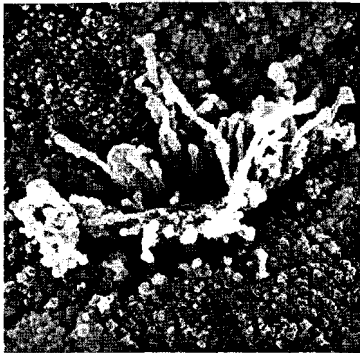
Microbial Ecology 849

- 21.1** Microbial Communities: Omics Analysis 850
- 21.2** Functional Ecology: Microbial Culture and Abiotic Factors 861
- 21.3** Symbiosis 869
- 21.4** Animal Digestive Microbiomes 876
- 21.5** Marine and Freshwater Microbes 883
 - Special Topic 21** Marine Biofilm Bacteria Eat Plasticizers 890
- 21.6** Soil and Plant Microbial Communities 896
 - eResearch Activity 21** What Builds Hedgehogs and Corncobs on Your Teeth? 

CHAPTER 22

Element Cycles and Environmental Microbiology 909

- 22.1** The Carbon Cycle and Climate Change 910
- 22.2** The Hydrologic Cycle and Wastewater Treatment 921
- 22.3** The Nitrogen Cycle 927
- 22.4** Sulfur, Phosphorus, and Metals 933
- 22.5** Our Built Environment 939
 - Special Topic 22** A Microbial Jungle in a Kitchen Sponge 942
- 22.6** Astrobiology 945
 - eResearch Activity 22** Look Up: Can We See Life on Distant Planets? 



PART 5

Medicine and Immunology

CHAPTER 23

The Human Microbiome and Innate Immunity 953

- 23.1 The Human Microbiome 954
- 23.2 Benefits and Risks of Microbiota 963
- 23.3 Overview of the Immune System 970
 - Special Topic 23** Why Do Tattoos Last Forever? 976
- 23.4 Physical and Chemical Defenses against Infection 980
- 23.5 Innate Immunity: Surveillance, Cytokines, and Inflammation 984
- 23.6 Complement and Fever 993
 - eResearch Activity 23** Can Altering the Gut Microbiome Affect Memory? 

CHAPTER 24

The Adaptive Immune Response 999

- 24.1 Overview of Adaptive Immunity 1000
- 24.2 Antibody Structure, Diversity, and Synthesis 1006
- 24.3 T Cells Link Antibody and Cellular Immune Systems 1018
- 24.4 Complement as Part of Adaptive Immunity 1030
- 24.5 Gut Mucosal Immunity and the Microbiome 1032
- 24.6 Immunization 1035
- 24.7 Hypersensitivity and Autoimmunity 1039
 - Special Topic 24** A Monoclonal Magic Bullet for Ebola? 1040
 - eResearch Activity 24** Can a Subset of Regulatory T Cells Prevent Allergies and Autoimmunity? 

CHAPTER 25

Pathogenesis 1051

- 25.1 Host-Pathogen Interactions 1052
- 25.2 Microbial Attachment: First Contact 1061
- 25.3 Toxins Subvert Host Functions 1066
 - Special Topic 25** Chronic Staph Infections Work with a NET 1070
- 25.4 Deploying Toxins and Effectors 1078
- 25.5 Surviving within the Host 1082
- 25.6 Tools Used to Probe Pathogenesis 1095
 - eResearch Activity 25** Why Does *Shigella* “Prefer” Humans and Gorillas over Other Mammals? 

CHAPTER 26

Microbial Diseases 1101

- 26.1 Basics of Diagnosis and Infections of Skin, Soft Tissue, and Bone 1102
- 26.2 Respiratory Tract Infections 1109
- 26.3 Gastrointestinal Tract Infections 1120
- 26.4 Genitourinary Tract Infections 1132
- 26.5 Cardiovascular and Systemic Infections 1142
- Special Topic 26** How Neutrophils Ambush *Staphylococcus aureus* in a Lymph Node 1144
- 26.6 Central Nervous System Infections 1154
- eResearch Activity 26** Can a Microbiome “Learn” from an Infection? 

CHAPTER 27

Antimicrobial Therapy and Discovery 1165

- 27.1 Fundamentals of Antimicrobial Therapy 1166
- 27.2 Antibiotic Mechanisms of Action 1173
- 27.3 Challenges of Drug Resistance and Discovery 1185
- Special Topic 27** Artificial Intelligence Tackles the Superbug Threat 1198
- 27.4 Antiviral Agents 1201
- 27.5 Antifungal Agents 1209
- eResearch Activity 27** Can a Selective, Narrow-Spectrum Antibiotic for Lyme Disease Be Found? 

CHAPTER 28

Clinical Microbiology and Epidemiology 1215

- 28.1 Clinical Specimen Collection and Handling 1216
- 28.2 Pathogen Identification by Culture and Phenotype 1222
- 28.3 Molecular and Serological Identification of Pathogens 1230
- Special Topic 28** Next-Generation Diagnostics: CRISPR Launches a “Flare” 1236
- 28.4 Epidemiology 1244
- 28.5 Detecting Emerging Microbial Diseases 1251
- 28.6 Infectious Disease and Health Disparities 1259
- eResearch Activity 28** How Does SARS-CoV-2 Evolve in the Human Host? 

Glossary G-1

Credits C-1

Index I-1