

Brief Contents

UNIT 1 Principles of Microbiology

| | | |
|-----------|---|-----|
| Chapter 1 | Microorganisms and Microbiology | 1 |
| Chapter 2 | A Brief Journey to the Microbial World | 25 |
| Chapter 3 | Chemistry of Cellular Components | 50 |
| Chapter 4 | Cell Structure and Function in <i>Bacteria</i> and <i>Archaea</i> | 66 |
| Chapter 5 | Nutrition, Culture, and Metabolism of Microorganisms | 107 |
| Chapter 6 | Microbial Growth | 141 |

UNIT 2 Molecular Biology of Microorganisms

| | | |
|------------|---|-----|
| Chapter 7 | Essentials of Molecular Biology | 175 |
| Chapter 8 | Archaeal and Eukaryotic Molecular Biology | 207 |
| Chapter 9 | Regulation of Gene Expression | 224 |
| Chapter 10 | Overview of Viruses and Virology | 251 |
| Chapter 11 | Principles of Bacterial Genetics | 278 |
| Chapter 12 | Genetic Engineering | 313 |
| Chapter 13 | Microbial Genomics | 343 |

UNIT 3 Microbial Diversity

| | | |
|------------|---|-----|
| Chapter 14 | Microbial Evolution and Systematics | 367 |
| Chapter 15 | <i>Bacteria</i> : The <i>Proteobacteria</i> | 398 |
| Chapter 16 | <i>Bacteria</i> : Gram-Positive and Other <i>Bacteria</i> | 445 |
| Chapter 17 | <i>Archaea</i> | 487 |
| Chapter 18 | Eukaryotic Cell Biology and Eukaryotic Microorganisms | 516 |
| Chapter 19 | Viral Diversity | 548 |

UNIT 4 Metabolic Diversity and Microbial Ecology

| | | |
|------------|---|-----|
| Chapter 20 | Metabolic Diversity: Phototrophy, Autotrophy, Chemolithotrophy, and Nitrogen Fixation | 578 |
| Chapter 21 | Metabolic Diversity: Catabolism of Organic Compounds | 612 |

| | | |
|------------|--|-----|
| Chapter 22 | Methods in Microbial Ecology | 652 |
| Chapter 23 | Microbial Ecosystems | 673 |
| Chapter 24 | Nutrient Cycles, Bioremediation, and Symbioses | 694 |

UNIT 5 Putting Microorganisms to Work

| | | |
|------------|-------------------------|-----|
| Chapter 25 | Industrial Microbiology | 733 |
| Chapter 26 | Biotechnology | 761 |

UNIT 6 Antimicrobial Agents and Pathogenicity

| | | |
|------------|------------------------------------|-----|
| Chapter 27 | Microbial Growth Control | 779 |
| Chapter 28 | Microbial Interactions with Humans | 811 |

UNIT 7 Immunology

| | | |
|------------|--|-----|
| Chapter 29 | Essentials of Immunology | 839 |
| Chapter 30 | Immunology in Host Defense and Disease | 865 |
| Chapter 31 | Molecular Immunology | 881 |

UNIT 8 Diagnosing and Tracking Infectious Diseases

| | | |
|------------|--|-----|
| Chapter 32 | Diagnostic Microbiology and Immunology | 900 |
| Chapter 33 | Epidemiology | 934 |

UNIT 9 Microbial Diseases

| | | |
|------------|---|------|
| Chapter 34 | Person-to-Person Microbial Diseases | 964 |
| Chapter 35 | Vectorborne and Soilborne Microbial Diseases | 1002 |
| Chapter 36 | Wastewater Treatment, Water Purification, and Waterborne Microbial Diseases | 1025 |
| Chapter 37 | Food Preservation and Foodborne Microbial Diseases | 1043 |

Contents

Preface v

UNIT 1 PRINCIPLES OF MICROBIOLOGY

Chapter 1 Microorganisms and Microbiology 1

I INTRODUCTION TO MICROBIOLOGY 2

- 1.1 Microbiology 2
- 1.2 Microorganisms as Cells 3
- 1.3 Microorganisms and Their Natural Environments 5
- 1.4 The Antiquity and Extent of Microbial Life 6
- 1.5 The Impact of Microorganisms on Humans 7

II PATHWAYS OF DISCOVERY IN MICROBIOLOGY 10

- 1.6 The Historical Roots of Microbiology: Hooke, van Leeuwenhoek, and Cohn 10
- 1.7 Pasteur and the Defeat of Spontaneous Generation 12
- 1.8 Koch, Infectious Disease, and Pure Culture Microbiology 14
- 1.9 Microbial Diversity and the Rise of General Microbiology 18
- 1.10 The Modern Era of Microbiology 20

Microbial Sidebar
Solid Media, the Petri Plate, and Pure Cultures 17

Chapter 2 A Brief Journey to the Microbial World 25

I SEEING THE VERY SMALL 26

- 2.1 Some Principles of Light Microscopy 26
- 2.2 Improving and Adjusting Contrast in Light Microscopy 27
- 2.3 Imaging Cells in Three Dimensions 30
- 2.4 Electron Microscopy 31

II CELL STRUCTURE AND EVOLUTIONARY HISTORY 33

- 2.5 Elements of Cell and Viral Structure 33
- 2.6 Arrangement of DNA in Microbial Cells 35
- 2.7 The Evolutionary Tree of Life 37

III MICROBIAL DIVERSITY 38

- 2.8 Physiological Diversity of Microorganisms 39
- 2.9 *Bacteria* 40
- 2.10 *Archaea* 44
- 2.11 Eukaryotic Microorganisms 45

Chapter 3 Chemistry of Cellular Components 50

I CHEMICAL BONDING, MACROMOLECULES, AND WATER 51

- 3.1 Strong and Weak Chemical Bonds 51
- 3.2 An Overview of Macromolecules and Water as the Solvent of Life 52

II NONINFORMATIONAL MACROMOLECULES 55

- 3.3 Polysaccharides 55
- 3.4 Lipids 56

III INFORMATIONAL MACROMOLECULES 57

- 3.5 Nucleic Acids 57
- 3.6 Amino Acids and the Peptide Bond 59
- 3.7 Proteins: Primary and Secondary Structure 61
- 3.8 Proteins: Higher Order Structure and Denaturation 62

Chapter 4 Cell Structure and Function in Bacteria and Archaea 66

I CELL SHAPE AND SIZE 67

- 4.1 Cell Morphology 67
- 4.2 Cell Size and the Significance of Smallness 68

II THE CYTOPLASMIC MEMBRANE AND TRANSPORT 70

- 4.3 The Cytoplasmic Membrane in *Bacteria* and *Archaea* 70
- 4.4 The Functions of Cytoplasmic Membranes 73
- 4.5 Transport and Transport Systems 75

III CELL WALLS OF PROKARYOTES 78

- 4.6 The Cell Wall of *Bacteria*: Peptidoglycan 78
- 4.7 The Outer Membrane of Gram-Negative *Bacteria* 82
- 4.8 Cell Walls of *Archaea* 84

IV OTHER CELL SURFACE STRUCTURES AND INCLUSIONS 86

- 4.9 Cell Surface Layers, Pili, and Fimbriae 86
- 4.10 Cell Inclusions 87
- 4.11 Gas Vesicles 89
- 4.12 Endospores 91

V MICROBIAL LOCOMOTION 95

- 4.13 Flagella and Motility 96
- 4.14 Gliding Motility 100
- 4.15 Cell Motion as a Behavioral Response: Microbial Taxes 102

Microbial Sidebar
How Long Can an Endospore Survive? 94

Chapter 5 Nutrition, Culture, and Metabolism of Microorganisms 107

- I** NUTRITION AND CULTURE OF MICROORGANISMS 108
- 5.1 Microbial Nutrition 108
- 5.2 Culture Media 111
- 5.3 Laboratory Culture of Microorganisms 113
- II** ENERGETICS AND ENZYMES 114
- 5.4 Bioenergetics 114
- 5.5 Catalysis and Enzymes 116
- III** OXIDATION-REDUCTION AND ENERGY-RICH COMPOUNDS 118
- 5.6 Oxidation-Reduction: Electron Donors and Electron Acceptors 118
- 5.7 NAD as a Redox Electron Carrier 119
- 5.8 Energy-Rich Compounds and Energy Storage 121
- IV** ESSENTIALS OF CATABOLISM 122
- 5.9 Energy Conservation 122
- 5.10 Glycolysis as an Example of Fermentation 122
- 5.11 Respiration and Membrane-Associated Electron Carriers 126
- 5.12 Respiration and the Proton Motive Force 127
- 5.13 Carbon Flow in Respiration: The Citric Acid Cycle 130
- 5.14 Catabolic Diversity 131
- V** ESSENTIALS OF ANABOLISM 133
- 5.15 Biosynthesis of Sugars and Polysaccharides 133
- 5.16 Biosynthesis of Amino Acids and Nucleotides 134
- 5.17 Biosynthesis of Fatty Acids and Lipids 135
- 5.18 Regulation of Activity of Biosynthetic Enzymes 136

Microbial Sidebar

The Products of Yeast Fermentation and the Pasteur Effect 125

Chapter 6 Microbial Growth 141

- I** BACTERIAL CELL DIVISION 142
- 6.1 Cell Growth and Binary Fission 142
- 6.2 Fts Proteins and Cell Division 142
- 6.3 MreB and Determinants of Cell Morphology 144
- 6.4 Peptidoglycan Synthesis and Cell Division 145
- II** GROWTH OF BACTERIAL POPULATIONS 147
- 6.5 Growth Terminology and the Concept of Exponential Growth 147
- 6.6 The Mathematics of Exponential Growth 148
- 6.7 The Microbial Growth Cycle 149
- 6.8 Continuous Culture: The Chemostat 151
- III** MEASURING MICROBIAL GROWTH 152
- 6.9 Measurements of Total Cell Numbers: Microscopic Counts 153
- 6.10 Viable Cell Counting 153
- 6.11 Measurements of Microbial Mass: Turbidimetric Methods 156

- IV** TEMPERATURE AND MICROBIAL GROWTH 157
- 6.12 Effect of Temperature on Microbial Growth 157
- 6.13 Microbial Growth at Cold Temperatures 159
- 6.14 Microbial Growth at High Temperatures 162

- V** OTHER ENVIRONMENTAL FACTORS AFFECTING GROWTH 165
- 6.15 Microbial Growth at Low or High pH 165
- 6.16 Osmotic Effects on Microbial Growth 166
- 6.17 Oxygen and Microbial Growth 168
- 6.18 Toxic Forms of Oxygen 171

Microbial Sidebar

Microbial Growth in the Real World: Biofilms 158

UNIT 2 MOLECULAR BIOLOGY OF MICROORGANISMS

Chapter 7 Essentials of Molecular Biology 175

- I** GENES AND GENE EXPRESSION 176
- 7.1 Macromolecules and Genetic Information 176
- II** DNA STRUCTURE 177
- 7.2 The Double Helix 177
- 7.3 Supercoiling 180
- 7.4 Chromosomes and Other Genetic Elements 181
- III** DNA REPLICATION 182
- 7.5 Templates and Enzymes 182
- 7.6 The Replication Fork 184
- 7.7 Bidirectional Replication and the Replisome 186
- 7.8 Proofreading and Termination 188
- IV** RNA SYNTHESIS: TRANSCRIPTION 189
- 7.9 Overview of Transcription 189
- 7.10 Sigma Factors and Consensus Sequences 191
- 7.11 Termination of Transcription 192
- 7.12 The Unit of Transcription 193
- V** PROTEIN SYNTHESIS 194
- 7.13 The Genetic Code 195
- 7.14 Transfer RNA 196
- 7.15 Translation: The Process of Protein Synthesis 199
- 7.16 The Incorporation of Nonstandard Amino Acids 202
- 7.17 Folding and Secreting Proteins 202

Chapter 8 Archaeal and Eukaryotic Molecular Biology 207

- I** MOLECULAR BIOLOGY OF ARCHAEA 208
- 8.1 Chromosomes and DNA Replication in the Archaea 208

8.2 Transcription and RNA Processing in *Archaea* 209

8.3 Protein Synthesis in *Archaea* 211

8.4 Shared Features of *Bacteria* and *Archaea* 211

II EUKARYOTIC GENETICS AND MOLECULAR BIOLOGY 213

8.5 Genes and Chromosomes in *Eukarya* 213

8.6 Overview of Eukaryotic Cell Division 214

8.7 Replication of Linear DNA 215

8.8 RNA Processing 216

8.9 Transcription and Translation in the *Eukarya* 220

8.10 RNA Interference (RNAi) 222

Microbial Sidebar
Inteins and Protein Splicing 218

Chapter 9 Regulation of Gene Expression 224

I OVERVIEW OF REGULATION 225

9.1 Major Modes of Regulation 225

II DNA-BINDING PROTEINS AND REGULATION OF TRANSCRIPTION 225

9.2 DNA-Binding Proteins 226

9.3 Negative Control of Transcription: Repression and Induction 228

9.4 Positive Control of Transcription 230

III SENSING AND SIGNAL TRANSDUCTION 231

9.5 Two-Component Regulatory Systems 231

9.6 Quorum Sensing 233

9.7 Regulation of Chemotaxis 235

9.8 Control of Transcription in *Archaea* 236

IV GLOBAL REGULATORY MECHANISMS 237

9.9 Global Control and the *lac* Operon 237

9.10 The Stringent Response 239

9.11 Other Global Control Networks 240

V REGULATION OF DEVELOPMENT IN MODEL BACTERIA 242

9.12 Sporulation in *Bacillus* 242

9.13 *Caulobacter* Differentiation 243

VI RNA-BASED REGULATION 244

9.14 RNA Regulation and Antisense RNA 244

9.15 Riboswitches 245

9.16 Attenuation 246

Chapter 10 Overview of Viruses and Virology 251

I VIRUS STRUCTURE AND GROWTH 252

10.1 General Properties of Viruses 252

10.2 Nature of the Virion 253

10.3 The Virus Host 256

10.4 Quantification of Viruses 257

II VIRAL REPLICATION 258

10.5 General Features of Virus Replication 258

10.6 Viral Attachment and Penetration 259

10.7 Production of Viral Nucleic Acid and Protein 261

III VIRAL DIVERSITY 263

10.8 Overview of Bacterial Viruses 263

10.9 Virulent Bacteriophages and T4 264

10.10 Temperate Bacteriophages, Lambda and P1 267

10.11 Overview of Animal Viruses 270

10.12 Retroviruses 271

IV SUBVIRAL ENTITIES 273

10.13 Defective Viruses 273

10.14 Viroids 274

10.15 Prions 275

Microbial Sidebar
Did Viruses Invent DNA? 264

Chapter 11 Principles of Bacterial Genetics 278

I BACTERIAL CHROMOSOMES AND PLASMIDS 279

11.1 Genetic Map of the *Escherichia coli* Chromosome 279

11.2 Plasmids: General Principles 282

11.3 Types of Plasmids and Their Biological Significance 283

II MUTATION 285

11.4 Mutations and Mutants 285

11.5 Molecular Basis of Mutation 287

11.6 Mutation Rates 290

11.7 Mutagenesis 290

11.8 Mutagenesis and Carcinogenesis: The Ames Test 293

III GENETIC EXCHANGE IN PROKARYOTES 294

11.9 Genetic Recombination 295

11.10 Transformation 297

11.11 Transduction 299

11.12 Conjugation: Essential Features 301

11.13 The Formation of Hfr Strains and Chromosome Mobilization 303

11.14 Complementation 306

11.15 Gene Transfer in *Archaea* 308

11.16 Mobile DNA: Transposable Elements 309

Chapter 12 Genetic Engineering 313

I TOOLS AND TECHNIQUES OF GENETIC ENGINEERING 314

12.1 Restriction and Modification Enzymes 314

12.2 Nucleic Acid Hybridization and the Southern Blot 316

12.3 Essentials of Molecular Cloning 316

12.4 Plasmids as Cloning Vectors 318

II SEQUENCING, SYNTHESIS, AND AMPLIFICATION OF DNA 320

12.5 Sequencing DNA 320

Chapter 12 (continued)

- 12.6 Sequencing and Annotating Entire Genomes 322
- 12.7 Synthesizing DNA 323
- 12.8 Amplifying DNA: The Polymerase Chain Reaction 324
- III BACTERIAL GENE MANIPULATION 327**
- 12.9 Molecular Methods for Mutagenesis 327
- 12.10 Gene Fusions and Reporter Genes 329
- IV ADVANCED CLONING TECHNIQUES 330**
- 12.11 Hosts for Cloning Vectors 330
- 12.12 Finding the Right Clone 332
- 12.13 Shuttle Vectors and Expression Vectors 334
- 12.14 Bacteriophage Lambda as a Cloning Vector 337
- 12.15 Vectors for Genomic Cloning and Sequencing 338
- Microbial Sidebar**
DNA Fingerprinting 326

Chapter 13 Microbial Genomics 343

- I MICROBIAL GENOMES 344**
- 13.1 A Short History of Genomics 344
- 13.2 Prokaryotic Genomes: Sizes and ORF Contents 344
- 13.3 Prokaryotic Genomes: Bioinformatic Analyses and Gene Distributions 347
- 13.4 The Genomes of Eukaryotic Organelles 350
- 13.5 Eukaryotic Microbial Genomes 353
- II GENOME FUNCTION AND REGULATION 355**
- 13.6 Microarrays and the Transcriptome 355
- 13.7 Proteomics 357
- 13.8 Metabolomics 358
- III THE EVOLUTION OF GENOMES 359**
- 13.9 Gene Families, Duplications, and Deletions 359
- 13.10 Mobile DNA: Transposons and Insertion Sequences 360
- 13.11 Horizontal Gene Transfer and Genome Stability 361
- 13.12 Evolution of Virulence: Pathogenicity Islands 362
- IV ENVIRONMENTAL GENOMICS 364**
- 13.13 Detecting Uncultured Microorganisms 364
- 13.14 Viral Genomes in Nature 364
- Microbial Sidebar**
RNA Editing 352

UNIT 3 MICROBIAL DIVERSITY**Chapter 14 Microbial Evolution and Systematics 367**

- I EARLY EARTH AND THE ORIGIN AND DIVERSIFICATION OF LIFE 368**
- 14.1 Formation and Early History of Earth 368
- 14.2 Origin of Cellular Life 369

- 14.3 Microbial Diversification: Consequences for Earth's Biosphere 373
- 14.4 Endosymbiotic Origin of Eukaryotes 374

II MICROBIAL EVOLUTION 377

- 14.5 The Evolutionary Process 377
- 14.6 Evolutionary Analysis: Theoretical Aspects 377
- 14.7 Evolutionary Analysis: Analytical Methods 379
- 14.8 Microbial Phylogeny 381
- 14.9 Applications of SSU rRNA Phylogenetic Methods 384

III MICROBIAL SYSTEMATICS 385

- 14.10 Phenotypic Analysis 385
- 14.11 Genotypic Analysis 387
- 14.12 Phylogenetic Analysis 389
- 14.13 The Species Concept in Microbiology 390
- 14.14 Classification and Nomenclature 393

Chapter 15 Bacteria: The Proteobacteria 398**I THE PHYLOGENY OF BACTERIA 399**

- 15.1 Phylogenetic Overview of *Bacteria* 399

II PHOTOTROPHIC, CHEMOLITHOTROPHIC, AND METHANOTROPHIC PROTEOBACTERIA 400

- 15.2 Purple Phototrophic Bacteria 401
- 15.3 The Nitrifying Bacteria 403
- 15.4 Sulfur- and Iron-Oxidizing Bacteria 405
- 15.5 Hydrogen-Oxidizing Bacteria 408
- 15.6 Methanotrophs and Methylophiles 410

III AEROBIC AND FACULTATIVELY AEROBIC CHEMOORGANOTROPHIC PROTEOBACTERIA 413

- 15.7 *Pseudomonas* and the Pseudomonads 413
- 15.8 Acetic Acid Bacteria 415
- 15.9 Free-Living Aerobic, Nitrogen-Fixing Bacteria 416
- 15.10 *Neisseria*, *Chromobacterium*, and Relatives 418
- 15.11 Enteric Bacteria 419
- 15.12 *Vibrio*, *Aliivibrio*, and *Photobacterium* 423
- 15.13 Rickettsias 425

IV MORPHOLOGICALLY UNUSUAL PROTEOBACTERIA 427

- 15.14 Spirilla 427
- 15.15 Sheathed *Proteobacteria*: *Sphaerotilus* and *Leptothrix* 430
- 15.16 Budding and Prosthecate/Stalked Bacteria 431

V DELTA- AND EPSILONPROTEOBACTERIA 436

- 15.17 Gliding Myxobacteria 436
- 15.18 Sulfate- and Sulfur-Reducing *Proteobacteria* 438
- 15.19 The *Epsilonproteobacteria* 441

Chapter 16 Bacteria: Gram-Positive and Other Bacteria 445**I OVERVIEW OF GRAM-POSITIVE AND OTHER BACTERIA 446**

- II** GRAM-POSITIVE BACTERIA AND ACTINOBACTERIA 446
- 16.1 Nonsporulating, Gram-Positive Bacteria 446
- 16.2 Endospore-Forming Gram-Positive Bacteria 450
- 16.3 Cell Wall-Less Gram-Positive Bacteria: The Mycoplasmas 451
- 16.4 Actinobacteria: Coryneform and Propionic Acid Bacteria 456
- 16.5 Actinobacteria: *Mycobacterium* 457
- 16.6 Filamentous Actinobacteria: *Streptomyces* and Relatives 459
- III** CYANOBACTERIA AND PROCHLOROPHYTES 463
- 16.7 Cyanobacteria 463
- 16.8 Prochlorophytes 467
- IV** CHLAMYDIA 468
- 16.9 The Chlamydia 468
- V** PLANCTOMYCES/PIRELLULA
- 16.10 *Planctomyces*: A Phylogenetically Unique Stalked Bacterium 470
- VI** THE VERRUCOMICROBIA 471
- 16.11 *Verrucomicrobium* and *Prostheobacter* 471
- VII** THE FLAVOBACTERIA 472
- 16.12 *Bacteroides* and *Flavobacterium* 472
- 16.13 Acidobacteria 473
- VIII** THE CYTOPHAGA GROUP 473
- 16.14 *Cytophaga* and Relatives 473
- IX** GREEN SULFUR BACTERIA 474
- 16.15 *Chlorobium* and Other Green Sulfur Bacteria 474
- X** THE SPIROCHETES 477
- 16.16 Spirochetes 477
- XI** DEINOCOCCI 480
- 16.17 *Deinococcus* and *Thermus* 480
- XII** THE GREEN NONSULFUR BACTERIA 481
- 16.18 *Chloroflexus* and Relatives 481
- XIII** HYPERTHERMOPHILIC BACTERIA 483
- 16.19 *Thermotoga* and *Thermodesulfobacterium* 483
- 16.20 *Aquifex*, *Thermocrinis*, and Relatives 484
- XIV** NITROSPIRA AND DEFERRIBACTER 485
- 16.21 *Nitrospira*, *Deferribacter*, and Relatives 485

Chapter 17 Archaea 487

- I** PHYLOGENY AND GENERAL METABOLISM 488
- 17.1 Phylogenetic Overview of Archaea 488
- 17.2 Energy Conservation and Autotrophy in Archaea 489
- II** EURYARCHAEOTA 490
- 17.3 Extremely Halophilic Archaea 490

- 17.4 Methane-Producing Archaea: Methanogens 494
- 17.5 *Thermoplasmatales* 498
- 17.6 *Thermococcales* and *Methanopyrus* 499
- 17.7 *Archaeoglobales* 500
- 17.8 *Nanoarchaeum* and *Aciduliprofundum* 501

- III** CRENARCHAEOTA 503
- 17.9 Habitats and Energy Metabolism of *Crenarchaeota* 503
- 17.10 Hyperthermophiles from Terrestrial Volcanic Habitats 504
- 17.11 Hyperthermophiles from Submarine Volcanic Habitats 506
- 17.12 Nonthermophilic *Crenarchaeota* 509

- IV** EVOLUTION AND LIFE AT HIGH TEMPERATURES 510
- 17.13 An Upper Temperature Limit for Microbial Life 510
- 17.14 Adaptations to Life at High Temperature 511
- 17.15 Hyperthermophilic Archaea, H₂, and Microbial Evolution 513

Chapter 18 Eukaryotic Cell Biology and Eukaryotic Microorganisms 516

- I** EUKARYOTIC CELL STRUCTURE AND FUNCTION 517
- 18.1 Eukaryotic Cell Structure and the Nucleus 517
- 18.2 Respiratory and Fermentative Organelles: The Mitochondrion and the Hydrogenosome 518
- 18.3 Photosynthetic Organelle: The Chloroplast 519
- 18.4 Endosymbiosis: Relationships of Mitochondria and Chloroplasts to Bacteria 520
- 18.5 Other Organelles and Eukaryotic Cell Structures 522
- II** EUKARYOTIC MICROBIAL DIVERSITY 524
- 18.6 Phylogeny of the Eukarya 524
- III** PROTISTS 526
- 18.7 Diplomonads and Parabasalids 526
- 18.8 Euglenozoans 527
- 18.9 Alveolates 528
- 18.10 Stramenopiles 530
- 18.11 Cercozoans and Radiolarians 531
- 18.12 Amoebozoa 532
- IV** FUNGI 535
- 18.13 Fungal Physiology, Structure, and Associations with Other Organisms 535
- 18.14 Fungal Reproduction and Phylogeny 537
- 18.15 Chytridiomycetes 539
- 18.16 Zygomycetes 539
- 18.17 Glomeromycetes 540
- 18.18 Ascomycetes 540
- 18.19 Basidiomycetes 542
- V** UNICELLULAR RED AND GREEN ALGAE 543
- 18.20 Unicellular Red Algae 543
- 18.21 Unicellular Green Algae 544

Chapter 19 Viral Diversity 548

- I VIRUSES OF BACTERIA 549**
- 19.1 RNA Bacteriophages 549
- 19.2 Single-Stranded DNA Bacteriophages 550
- 19.3 Double-Stranded DNA Bacteriophages 553
- 19.4 Mu: A Double-Stranded Transposable DNA Bacteriophage 555
- II VIRUSES OF ARCHAEA 557**
- 19.5 Viruses of *Archaea* 557
- III RNA VIRUSES OF EUKARYOTES 558**
- 19.6 Plant RNA Viruses 558
- 19.7 Positive-Strand RNA Viruses of Animals: Poliovirus and Coronaviruses 559
- 19.8 Negative-Strand RNA Viruses of Animals: Rabies, Influenza, and Related Viruses 562
- 19.9 Double-Stranded RNA Viruses: Reoviruses 564
- IV DNA VIRUSES OF EUKARYOTES 565**
- 19.10 Plant DNA Viruses 565
- 19.11 Replication of Double-Stranded DNA Viruses of Animals 568
- 19.12 Double-Stranded DNA Viruses: Herpesviruses 569
- 19.13 Double-Stranded DNA Viruses: Pox Viruses 571
- 19.14 Double-Stranded DNA Viruses: Adenoviruses 572
- V VIRUSES THAT EMPLOY REVERSE TRANSCRIPTASE 573**
- 19.15 Retroviruses and Hepadnavirus 573
- Microbial Sidebar**
Mimivirus and Viral Evolution 566

UNIT 4 METABOLIC DIVERSITY AND MICROBIAL ECOLOGY**Chapter 20 Metabolic Diversity: Phototrophy, Autotrophy, Chemolithotrophy, and Nitrogen Fixation 578**

- I THE PHOTOTROPHIC WAY OF LIFE 579**
- 20.1 Photosynthesis 579
- 20.2 Chlorophylls and Bacteriochlorophylls 579
- 20.3 Carotenoids and Phycobilins 582
- 20.4 Anoxygenic Photosynthesis 585
- 20.5 Oxygenic Photosynthesis 589
- II AUTOTROPHY 591**
- 20.6 The Calvin Cycle 591
- 20.7 Other Autotrophic Pathways in Phototrophs 593
- III CHEMOLITHOTROPHY 595**
- 20.8 The Energetics of Chemolithotrophy 595
- 20.9 Hydrogen Oxidation 595
- 20.10 Oxidation of Reduced Sulfur Compounds 596
- 20.11 Iron Oxidation 599

- 20.12 Nitrification 602
- 20.13 Anammox 603
- IV NITROGEN FIXATION 604**
- 20.14 Nitrogenase and Nitrogen Fixation 604
- 20.15 Genetics and Regulation of N_2 Fixation 608

Microbial Sidebar
Winogradsky and Chemolithoautotrophy 597

Chapter 21 Metabolic Diversity: Catabolism of Organic Compounds 612

- I FERMENTATIONS 613**
- 21.1 Fermentations: Energetic and Redox Considerations 613
- 21.2 Fermentative Diversity: Lactic and Mixed-Acid Fermentations 615
- 21.3 Fermentative Diversity: Clostridial and Propionic Acid Fermentations 618
- 21.4 Fermentations without Substrate-Level Phosphorylation 620
- 21.5 Syntrophy 622
- II ANAEROBIC RESPIRATION 624**
- 21.6 Anaerobic Respiration: General Principles 624
- 21.7 Nitrate Reduction and Denitrification 625
- 21.8 Sulfate and Sulfur Reduction 627
- 21.9 Acetogenesis 630
- 21.10 Methanogenesis 631
- 21.11 Proton Reduction 635
- 21.12 Other Electron Acceptors 636
- 21.13 Anoxic Hydrocarbon Oxidation Linked to Anaerobic Respiration 639
- III AEROBIC CHEMOORGANOTROPHIC PROCESSES 641**
- 21.14 Molecular Oxygen as a Reactant in Biochemical Processes 641
- 21.15 Aerobic Hydrocarbon Oxidation 642
- 21.16 Methylophony and Methanotrophy 643
- 21.17 Hexose, Pentose, and Polysaccharide Metabolism 645
- 21.18 Organic Acid Metabolism 647
- 21.19 Lipid Metabolism 648

Chapter 22 Methods in Microbial Ecology 652

- I CULTURE-DEPENDENT ANALYSES OF MICROBIAL COMMUNITIES 653**
- 22.1 Enrichment and Isolation 653
- 22.2 Isolation in Pure Culture 657
- II CULTURE-INDEPENDENT ANALYSES OF MICROBIAL COMMUNITIES 658**
- 22.3 General Staining Methods 659
- 22.4 FISH 661
- 22.5 Linking Specific Genes to Specific Organisms Using PCR 662
- 22.6 Environmental Genomics 665

III MEASURING MICROBIAL ACTIVITIES IN NATURE 666

- 22.7 Chemical Assays, Radioisotopic Methods, and Microelectrodes 666
22.8 Stable Isotopes 669

Chapter 23 Microbial Ecosystems 673

I PRINCIPLES OF MICROBIAL ECOLOGY 674

- 23.1 Ecological Concepts 674
23.2 Microbial Ecosystems and Biogeochemical Cycling 675

II THE MICROBIAL HABITAT 676

- 23.3 Environments and Microenvironments 676
23.4 Biofilms: Microbial Growth on Surfaces 677
23.5 Biofilms: Advantages and Control 679

III FRESHWATER, SOIL, AND PLANT MICROBIAL ECOSYSTEMS 680

- 23.6 Freshwater Environments 680
23.7 Terrestrial Environments 682
23.8 Plants as Microbial Habitats 686

IV MARINE MICROBIAL ECOSYSTEMS 687

- 23.9 Open Oceans 687
23.10 The Deep Sea and Barophilism 690

Microbial Sidebar

Microbial Life Deep Underground 685

Chapter 24 Nutrient Cycles, Bioremediation, and Symbioses 694

I THE CARBON AND OXYGEN CYCLES 695

- 24.1 The Carbon Cycle 695
24.2 Syntrophy and Methanogenesis 697

II NITROGEN, SULFUR, AND IRON CYCLES 699

- 24.3 The Nitrogen Cycle 700
24.4 The Sulfur Cycle 701
24.5 The Iron Cycle 703

III MICROBIAL BIOREMEDIATION 705

- 24.6 Microbial Leaching of Ores 705
24.7 Mercury and Heavy Metal Transformations 708
24.8 Petroleum Biodegradation 709
24.9 Biodegradation of Xenobiotics 711

IV ANIMAL-MICROBIAL SYMBIOSES 714

- 24.10 The Rumen and Ruminant Animals 714
24.11 Hydrothermal Vent Microbial Ecosystems 717
24.12 Squid-*Aliivibrio* Symbiosis 720

V PLANT-MICROBIAL SYMBIOSES 721

- 24.13 Lichens and Mycorrhizae 722
24.14 *Agrobacterium* and Crown Gall Disease 724
24.15 The Legume-Root Nodule Symbiosis 725

UNIT 5 PUTTING MICROORGANISMS TO WORK

Chapter 25 Industrial Microbiology 733

I INDUSTRIAL MICROORGANISMS AND PRODUCT FORMATION 734

- 25.1 Industrial Microorganisms and Their Products 734
25.2 Primary and Secondary Metabolites 735
25.3 Characteristics of Large-Scale Fermentations 736
25.4 Scale-Up of Industrial Fermentations 738

II PRODUCTS FOR THE HEALTH INDUSTRY 739

- 25.5 Antibiotics: Isolation and Characterization 739
25.6 Industrial Production of Penicillins and Tetracyclines 742
25.7 Vitamins and Amino Acids 744
25.8 Steroids and Other Biotransformations 745
25.9 Enzymes as Industrial Products 747

III PRODUCTS FOR THE FOOD INDUSTRY 749

- 25.10 Wine 749
25.11 Brewing, Distilling, and Commodity Alcohol 751
25.12 Vinegar 755
25.13 Citric Acid and Other Organic Compounds 756
25.14 Yeast as a Food and Food Supplement 757
25.15 Mushrooms as a Food Source 758

Microbial Sidebar

Home Brew 753

Chapter 26 Biotechnology 761

I PRODUCTS FROM GENETIC ENGINEERING 762

- 26.1 Overview of Biotechnology 762
26.2 Expression of Mammalian Genes in Bacteria 762
26.3 Production of Hormones 765
26.4 Other Mammalian Proteins and Products 766
26.5 Genetically Engineered Vaccines 767
26.6 Mining Genomes 769

II TRANSGENIC ORGANISMS 770

- 26.7 Engineering Metabolic Pathways in Bacteria 770
26.8 Genetic Engineering of Animals 772
26.9 Gene Therapy in Humans 774
26.10 Transgenic Plants in Agriculture 775

Microbial Sidebar

Synthetic Biology and Bacterial Photography 771

UNIT 6 ANTIMICROBIAL AGENTS AND PATHOGENICITY

Chapter 27 Microbial Growth Control 779

I PHYSICAL ANTIMICROBIAL CONTROL 780

- 27.1 Heat Sterilization 780

Chapter 27 (continued)

- 27.2 Radiation Sterilization 783
- 27.3 Filter Sterilization 784
- II** CHEMICAL ANTIMICROBIAL CONTROL 786
- 27.4 Chemical Growth Control 786
- 27.5 Chemical Antimicrobial Agents for External Use 788
- III** ANTIMICROBIAL AGENTS USED *IN VIVO* 791
- 27.6 Synthetic Antimicrobial Drugs 793
- 27.7 Naturally Occurring Antimicrobial Drugs: Antibiotics 794
- 27.8 β -Lactam Antibiotics: Penicillins and Cephalosporins 795
- 27.9 Antibiotics from Prokaryotes 797
- IV** CONTROL OF VIRUSES AND EUKARYOTIC PATHOGENS 799
- 27.10 Antiviral Drugs 799
- 27.11 Antifungal Drugs 801
- V** ANTIMICROBIAL DRUG RESISTANCE AND DRUG DISCOVERY 802
- 27.12 Antimicrobial Drug Resistance 802
- 27.13 The Search for New Antimicrobial Drugs 806

Microbial Sidebar*Preventing Antimicrobial Drug Resistance* 790**Chapter 28 Microbial Interactions with Humans**

811

- I** BENEFICIAL MICROBIAL INTERACTIONS WITH HUMANS 812
- 28.1 Overview of Human–Microbial Interactions 812
- 28.2 Normal Microbial Flora of the Skin 813
- 28.3 Normal Microbial Flora of the Oral Cavity 814
- 28.4 Normal Microbial Flora of the Gastrointestinal Tract 817
- 28.5 Normal Microbial Flora of Other Body Regions 819
- II** HARMFUL MICROBIAL INTERACTIONS WITH HUMANS 822
- 28.6 Entry of the Pathogen into the Host 822
- 28.7 Colonization and Growth 824
- 28.8 Virulence 825
- III** VIRULENCE FACTORS AND TOXINS 828
- 28.9 Virulence Factors 828
- 28.10 Exotoxins 828
- 28.11 Enterotoxins 831
- 28.12 Endotoxins 833
- IV** HOST FACTORS IN INFECTION 834
- 28.13 Host Risk Factors for Infection 834
- 28.14 Innate Resistance to Infection 836

Microbial Sidebar*Probiotics* 820**UNIT 7 IMMUNOLOGY****Chapter 29 Essentials of Immunology**

839

- I** OVERVIEW OF IMMUNITY 840
- 29.1 Cells and Organs of the Immune System 840
- 29.2 The Innate Immune Response 843
- 29.3 Inflammation, Fever, and Septic Shock 846
- 29.4 The Adaptive Immune Response 848
- II** ANTIGENS AND ANTIGEN PRESENTATION 849
- 29.5 Immunogens and Antigens 849
- 29.6 Antigen Presentation to T Lymphocytes 850
- III** T LYMPHOCYTES 853
- 29.7 T-Cytotoxic Cells and Natural Killer Cells 853
- 29.8 T-Helper Cells: Activating the Immune Response 854
- IV** ANTIBODIES 855
- 29.9 Antibodies 855
- 29.10 Antibody Production 858
- 29.11 Complement, Antibodies, and Pathogen Destruction 860

Chapter 30 Immunology in Host Defense and Disease

865

- I** IMMUNITY AND HOST DEFENSE 866
- 30.1 Innate Immunity 866
- 30.2 Adaptive Immunity and T Cells 867
- 30.3 Adaptive Immunity and Antibodies 868
- II** IMMUNITY AND PREVENTION OF INFECTIOUS DISEASES 869
- 30.4 Natural Immunity 869
- 30.5 Artificial Immunity and Immunization 870
- 30.6 New Immunization Strategies 872
- III** IMMUNE RESPONSE DISEASES 873
- 30.7 Allergy, Hypersensitivity, and Autoimmunity 873
- 30.8 Superantigens 878

Microbial Sidebar*The Promise of New Vaccines* 875**Chapter 31 Molecular Immunology**

881

- I** RECEPTORS AND IMMUNITY 882
- 31.1 Innate Immunity and Pattern Recognition 882
- 31.2 Adaptive Immunity and the Immunoglobulin Superfamily 885

- II THE MAJOR HISTOCOMPATIBILITY COMPLEX (MHC) 886**
- 31.3 MHC Protein Structure 886
- 31.4 MHC Polymorphism and Antigen Binding 887
- III ANTIBODIES 888**
- 31.5 Antibody Proteins and Antigen Binding 888
- 31.6 Antibody Genes and Diversity 889
- IV T CELL RECEPTORS 891**
- 31.7 T Cell Receptors: Proteins, Genes, and Diversity 891
- V MOLECULAR SIGNALS IN IMMUNITY 893**
- 31.8 Clonal Selection and Tolerance 893
- 31.9 T Cell and B Cell Activation 895
- 31.10 Cytokines and Chemokines 896

Microbial Sidebar

Drosophila Toll Receptors—An Ancient Response to Infections 883

UNIT 8 DIAGNOSING AND TRACKING INFECTIOUS DISEASES

Chapter 32 Diagnostic Microbiology and Immunology 900

- I GROWTH-DEPENDENT DIAGNOSTIC METHODS 901**
- 32.1 Isolation of Pathogens from Clinical Specimens 901
- 32.2 Growth-Dependent Identification Methods 906
- 32.3 Antimicrobial Drug Susceptibility Testing 908
- 32.4 Safety in the Microbiology Laboratory 911
- II IMMUNOLOGY AND DIAGNOSTIC METHODS 913**
- 32.5 Immunoassays for Infectious Disease 913
- 32.6 Polyclonal and Monoclonal Antibodies 914
- 32.7 *In Vitro* Antigen–Antibody Reactions: Serology 917
- 32.8 Agglutination 919
- 32.9 Fluorescent Antibodies 920
- 32.10 Enzyme-Linked Immunosorbent Assay and Radioimmunoassay 922
- 32.11 Immunoblot Procedures 927
- III NUCLEIC ACID-BASED DIAGNOSTIC METHODS 929**
- 32.12 Nucleic Acid Probes and PCR 929

Chapter 33 Epidemiology 934

- I PRINCIPLES OF EPIDEMIOLOGY 935**
- 33.1 The Science of Epidemiology 935
- 33.2 The Vocabulary of Epidemiology 935
- 33.3 Disease Reservoirs and Epidemics 937
- 33.4 Infectious Disease Transmission 940
- 33.5 The Host Community 942

- II CURRENT EPIDEMICS 944**
- 33.6 The AIDS Pandemic 944
- 33.7 Healthcare-Associated Infections 945
- III EPIDEMIOLOGY AND PUBLIC HEALTH 947**
- 33.8 Public Health Measures for the Control of Disease 947
- 33.9 Global Health Considerations 950
- 33.10 Emerging and Reemerging Infectious Diseases 951
- 33.11 Biological Warfare and Biological Weapons 957
- 33.12 Anthrax as a Biological Weapon 960
- Microbial Sidebar**
- SARS as a Model of Epidemiological Success 958*

UNIT 9 MICROBIAL DISEASES

Chapter 34 Person-to-Person Microbial Diseases 964

- I AIRBORNE TRANSMISSION OF DISEASES 965**
- 34.1 Airborne Pathogens 965
- 34.2 Streptococcal Diseases 966
- 34.3 *Corynebacterium* and Diphtheria 969
- 34.4 *Bordetella* and Pertussis 970
- 34.5 *Mycobacterium*, Tuberculosis, and Hansen's Disease 971
- 34.6 *Neisseria meningitidis*, Meningitis, and Meningococemia 974
- 34.7 Viruses and Respiratory Infections 975
- 34.8 Colds 977
- 34.9 Influenza 979
- II DIRECT CONTACT TRANSMISSION OF DISEASES 982**
- 34.10 *Staphylococcus* 982
- 34.11 *Helicobacter pylori* and Gastric Ulcers 983
- 34.12 Hepatitis Viruses 984
- III SEXUALLY TRANSMITTED INFECTIONS 986**
- 34.13 Gonorrhea and Syphilis 987
- 34.14 Chlamydia, Herpes, Trichomoniasis, and Human Papillomavirus 990
- 34.15 Acquired Immunodeficiency Syndrome: AIDS and HIV 992

Chapter 35 Vectorborne and Soilborne Microbial Diseases 1002

- I ANIMAL-TRANSMITTED DISEASES 1003**
- 35.1 Rabies 1003
- 35.2 Hantavirus Syndromes 1005
- II ARTHROPOD-TRANSMITTED DISEASES 1007**
- 35.3 Rickettsial Diseases 1007
- 35.4 Lyme Disease 1010

Chapter 35 (continued)

- 35.5 Malaria **1012**
 35.6 West Nile Virus **1015**
 35.7 Plague **1017**

III SOILBORNE DISEASES 1019

- 35.8 Pathogenic Fungi **1019**
 35.9 Tetanus **1022**

Microbial Sidebar

Special Pathogens and Viral Hemorrhagic Fevers **1006**

Chapter 36 Wastewater Treatment, Water Purification, and Waterborne Microbial Diseases 1025**I WASTEWATER MICROBIOLOGY AND WATER PURIFICATION 1026**

- 36.1 Public Health and Water Quality **1026**
 36.2 Wastewater and Sewage Treatment **1028**
 36.3 Drinking Water Purification **1031**

II WATERBORNE MICROBIAL DISEASES 1033

- 36.4 Sources of Waterborne Infection **1033**
 36.5 Cholera **1035**
 36.6 Giardiasis and Cryptosporidiosis **1036**
 36.7 Legionellosis (Legionnaires' Disease) **1038**
 36.8 Typhoid Fever and Other Waterborne Diseases **1039**

Chapter 37 Food Preservation and Foodborne Microbial Diseases 1043**I FOOD PRESERVATION AND MICROBIAL GROWTH 1044**

- 37.1 Microbial Growth and Food Spoilage **1044**
 37.2 Food Preservation **1045**
 37.3 Fermented Foods **1048**

II MICROBIAL SAMPLING AND FOOD POISONING 1049

- 37.4 Foodborne Diseases and Microbial Sampling **1050**
 37.5 Staphylococcal Food Poisoning **1051**
 37.6 Clostridial Food Poisoning **1052**

III FOOD INFECTION 1054

- 37.7 Salmonellosis **1054**
 37.8 Pathogenic *Escherichia coli* **1055**
 37.9 *Campylobacter* **1057**
 37.10 Listeriosis **1058**
 37.11 Other Foodborne Infectious Diseases **1058**

Microbial Sidebar

Spinach and Escherichia coli O157:H7 **1056**

Appendix 1

Energy Calculations in Microbial Bioenergetics A-1

Appendix 2

Bergey's Manual of Systematic Bacteriology,
 Second Edition A-5

Glossary G-1

Photo Credits P-1

Index I-1