

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

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

8.2	Transcription and RNA Processing in <i>Archaea</i>	209
8.3	Protein Synthesis in <i>Archaea</i>	211
8.4	Shared Features of <i>Bacteria</i> and <i>Archaea</i>	211
II	EUKARYOTIC GENETICS AND MOLECULAR BIOLOGY	213
8.5	Genes and Chromosomes in <i>Eukarya</i>	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 <i>Eukarya</i>	220
8.10	RNA Interference (RNAi)	222
	Microbial Sidebar <i>Inteins and Protein Splicing</i>	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 <i>Archaea</i>	236
IV	GLOBAL REGULATORY MECHANISMS	237
9.9	Global Control and the <i>lac</i> 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 <i>Bacillus</i>	242
9.13	<i>Caulobacter</i> 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 <i>Did Viruses Invent DNA?</i>	264

Chapter 11 Principles of Bacterial Genetics 278

I	BACTERIAL CHROMOSOMES AND PLASMIDS	279
11.1	Genetic Map of the <i>Escherichia coli</i> 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 <i>Archaea</i>	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 Methylophs 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

- OVERVIEW OF GRAM-POSITIVE AND OTHER BACTERIA 446

II	GRAM-POSITIVE BACTERIA AND ACTINOBACTERIA	446	17.4	Methane-Producing Archaea: Methanogens	494
16.1	Nonsporulating, Gram-Positive Bacteria	446	17.5	<i>Thermoplasmatales</i>	498
16.2	Endospore-Forming Gram-Positive Bacteria	450	17.6	<i>Thermococcales</i> and <i>Methanopyrus</i>	499
16.3	Cell Wall-Less Gram-Positive Bacteria: The Mycoplasmas	451	17.7	<i>Archaeoglobales</i>	500
16.4	Actinobacteria: Coryneform and Propionic Acid Bacteria	456	17.8	<i>Nanoarchaeum</i> and <i>Aciduliprofundum</i>	501
16.5	Actinobacteria: <i>Mycobacterium</i>	457	III	CRENARCHAEOTA	503
16.6	Filamentous Actinobacteria: <i>Streptomyces</i> and Relatives	459	17.9	Habitats and Energy Metabolism of <i>Crenarchaeota</i>	503
III	CYANOBACTERIA AND PROCHLOROPHYTES	463	17.10	Hyperthermophiles from Terrestrial Volcanic Habitats	504
16.7	Cyanobacteria	463	17.11	Hyperthermophiles from Submarine Volcanic Habitats	506
16.8	Prochlorophytes	467	17.12	Nonthermophilic <i>Crenarchaeota</i>	509
IV	CHLAMYDIA	468	IV	EVOLUTION AND LIFE AT HIGH TEMPERATURES	510
16.9	The Chlamydia	468	17.13	An Upper Temperature Limit for Microbial Life	510
V	PLANCTOMYCES/PIRELLULA		17.14	Adaptations to Life at High Temperature	511
16.10	<i>Planctomyces</i> : A Phylogenetically Unique Stalked Bacterium	470	17.15	Hyperthermophilic <i>Archaea</i> , H_2 , and Microbial Evolution	513
VI	THE VERRUCOMICROBIA	471	Chapter 18	Eukaryotic Cell Biology and Eukaryotic Microorganisms	516
16.11	<i>Verrucomicrobium</i> and <i>Prostheco bacter</i>	471	I	EUKARYOTIC CELL STRUCTURE AND FUNCTION	517
VII	THE FLAVOBACTERIA	472	18.1	Eukaryotic Cell Structure and the Nucleus	517
16.12	<i>Bacteroides</i> and <i>Flavobacterium</i>	472	18.2	Respiratory and Fermentative Organelles: The Mitochondrion and the Hydrogenosome	518
16.13	Acidobacteria	473	18.3	Photosynthetic Organelle: The Chloroplast	519
VIII	THE CYTOPHAGA GROUP	473	18.4	Endosymbiosis: Relationships of Mitochondria and Chloroplasts to <i>Bacteria</i>	520
16.14	<i>Cytophaga</i> and Relatives	473	18.5	Other Organelles and Eukaryotic Cell Structures	522
IX	GREEN SULFUR BACTERIA	474	II	EUKARYOTIC MICROBIAL DIVERSITY	524
16.15	<i>Chlorobium</i> and Other Green Sulfur Bacteria	474	18.6	Phylogeny of the <i>Eukarya</i>	524
X	THE SPIROCHETES	477	III	PROTISTS	526
16.16	Spirochetes	477	18.7	Diplomonads and Parabasalids	526
XI	DEINOCOCCI	480	18.8	Euglenozoans	527
16.17	<i>Deinococcus</i> and <i>Thermus</i>	480	18.9	Alveolates	528
XII	THE GREEN NONSULFUR BACTERIA	481	18.10	Stramenopiles	530
16.18	<i>Chloroflexus</i> and Relatives	481	18.11	Cercozoans and Radiolarians	531
XIII	HYPERTHERMOPHILIC BACTERIA	483	18.12	Amoebozoa	532
16.19	<i>Thermotoga</i> and <i>Thermodesulfobacterium</i>	483	IV	FUNGI	535
16.20	<i>Aquifex</i> , <i>Thermocrinis</i> , and Relatives	484	18.13	Fungal Physiology, Structure, and Associations with Other Organisms	535
XIV	NITROSPIRA AND DEFERRIBACTER	485	18.14	Fungal Reproduction and Phylogeny	537
16.21	<i>Nitrospira</i> , <i>Deferribacter</i> , and Relatives	485	18.15	Chytridiomycetes	539
Chapter 17	Archaea	487	18.16	Zygomycetes	539
I	PHYLOGENY AND GENERAL METABOLISM	488	18.17	Glomeromycetes	540
17.1	Phylogenetic Overview of <i>Archaea</i>	488	18.18	Ascomycetes	540
17.2	Energy Conservation and Autotrophy in <i>Archaea</i>	489	18.19	Basidiomycetes	542
II	EURYARCHAEOTA	490	V	UNICELLULAR RED AND GREEN ALGAE	543
17.3	Extremely Halophilic <i>Archaea</i>	490	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 N₂ 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 Methyloctrophy 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

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	
	<i>Drosophila Toll Receptors—An Ancient Response to Infections</i>	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	
	<i>SARS as a Model of Epidemiological Success</i>	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	<i>Corynebacterium</i> and Diphtheria	969
34.4	<i>Bordetella</i> and Pertussis	970
34.5	<i>Mycobacterium</i>, Tuberculosis, and Hansen's Disease	971
34.6	<i>Neisseria meningitidis</i>, Meningitis, and Meningococcemia	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	<i>Staphylococcus</i>	982
34.11	<i>Helicobacter pylori</i> 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**