

About the Authors iii

Preface iv

Part One Introduction to Microbiology

1 The Evolution of Microorganisms and Microbiology	1
1.1 Members of the Microbial World	1
1.2 Microbial Evolution	4
1.3 Microbiology and Its Origins	11
1.4 Microbiology Today	17
2 Microscopy	22
2.1 Lenses and the Bending of Light	22
2.2 Light Microscopes	23
2.3 Preparation and Staining of Specimens	31
2.4 Electron Microscopy	34
2.5 Scanning Probe Microscopy	39
3 Bacterial Cell Structure	42
3.1 The "Prokaryote" Controversy	42
3.2 A Typical Bacterial Cell	43
3.3 Bacterial Plasma Membranes	47
3.4 Bacterial Cell Walls	53
Microbial Diversity & Ecology 3.1	
Gram Positive and Gram Negative or Monoderms and Diderms?	54
3.5 Cell Envelope Layers Outside the Cell Wall	61
3.6 Bacterial Cytoplasm	62
3.7 External Structures	69
3.8 Bacterial Motility and Chemotaxis	72
3.9 Bacterial Endospores	76
4 Archaeal Cell Structure	82
4.1 A Typical Archaeal Cell	82
4.2 Archaeal Cell Envelopes	84
4.3 Archaeal Cytoplasm	87
4.4 External Structures	88
4.5 Comparison of <i>Bacteria</i> and <i>Archaea</i>	90
5 Eukaryotic Cell Structure	92
5.1 A Typical Eukaryotic Cell	92
5.2 Eukaryotic Cell Envelopes	94

5.3 Cytoplasm of Eukaryotes	96
5.4 Organelles of the Secretory and Endocytic Pathways	97
5.5 Organelles Involved in Genetic Control of the Cell	101
5.6 Organelles Involved in Energy Conservation	103
5.7 External Structures	104
Microbial Diversity & Ecology 5.1	
There Was an Old Woman Who Swallowed a Fly	106
5.8 Comparison of Bacterial, Archaeal, and Eukaryotic Cells	108
6 Viruses and Other Acellular Infectious Agents	112
6.1 Viruses	112
6.2 Virion Structure	113
Microbial Diversity & Ecology 6.1	
Host-Independent Growth of an Archaeal Virus	114
6.3 Viral Multiplication	119
6.4 Types of Viral Infections	124
6.5 Cultivation and Enumeration of Viruses	127
6.6 Viroids and Satellites	129
6.7 Prions	130

Part Two Microbial Nutrition, Growth, and Control

7 Microbial Growth	133
7.1 Reproductive Strategies	133
7.2 Bacterial Cell Cycle	134
Microbial Diversity & Ecology 7.1	
Cytokinesis Without FtsZ	137
7.3 Influences of Environmental Factors on Growth	141
7.4 Microbial Growth in Natural Environments	149
7.5 Laboratory Culture of Cellular Microbes	154
7.6 Growth Curve: When One Becomes Two and Two Become Four ...	160
7.7 Measurement of Microbial Population Size	164
7.8 Continuous Culture of Microorganisms	168
8 Control of Microorganisms in the Environment	172
8.1 Principles of Microbial Control	172
8.2 The Pattern of Microbial Death	174
8.3 Mechanical Removal Methods	175

Contents

8.4	Physical Control Methods	177	11.7	Anaerobic Respiration	247
8.5	Chemical Control Agents	180	11.8	Fermentation	248
8.6	Evaluation of Antimicrobial Agent Effectiveness	184	11.9	Catabolism of Organic Molecules Other Than Glucose	251
8.7	Biological Control of Microorganisms	186	11.10	Chemolithotrophy	253
9	Antimicrobial Chemotherapy	189		Microbial Diversity & Ecology 11.1	
9.1	The Development of Chemotherapy	189		Acid Mine Drainage	255
9.2	General Characteristics of Antimicrobial Drugs	190	11.11	Phototrophy	256
9.3	Determining the Level of Antimicrobial Activity	193	12	Anabolism: The Use of Energy in Biosynthesis	266
9.4	Antibacterial Drugs	195	12.1	Principles Governing Biosynthesis	266
9.5	Antifungal Drugs	201	12.2	Precursor Metabolites	268
9.6	Antiviral Drugs	203	12.3	CO ₂ Fixation	269
9.7	Antiprotozoan Drugs	205	12.4	Synthesis of Carbohydrates	272
9.8	Factors Influencing Antimicrobial Drug Effectiveness	206	12.5	Synthesis of Amino Acids	274
			12.6	Synthesis of Purines, Pyrimidines, and Nucleotides	281
			12.7	Lipid Synthesis	283
Part Three Microbial Metabolism					
10	Introduction to Metabolism	210			
10.1	Metabolism: Important Principles and Concepts	211	Part Four Microbial Molecular Biology and Genetics		
10.2	ATP: The Major Energy Currency of Cells	213	13	Bacterial Genome Replication and Expression	287
10.3	Redox Reactions: Reactions of Central Importance in Metabolism	215	13.1	DNA as Genetic Material	288
10.4	Electron Transport Chains: Sets of Sequential Redox Reactions	216	13.2	Nucleic Acid and Protein Structure	288
10.5	Biochemical Pathways	219	13.3	DNA Replication in Bacteria	293
10.6	Enzymes and Ribozymes	220	13.4	Bacterial Gene Structure	301
10.7	Regulation of Metabolism	224	13.5	Transcription in Bacteria	304
11	Catabolism: Energy Release and Conservation	230	13.6	The Genetic Code	309
11.1	Metabolic Diversity and Nutritional Types	230	13.7	Translation in Bacteria	311
11.2	Chemoorganotrophic Fueling Processes	232	13.8	Protein Maturation and Secretion	319
11.3	Aerobic Respiration	235	14	Regulation of Bacterial Cellular Processes	325
11.4	From Glucose to Pyruvate	235	14.1	Levels of Regulation	326
11.5	Tricarboxylic Acid Cycle	239	14.2	Regulation of Transcription Initiation	326
11.6	Electron Transport and Oxidative Phosphorylation	239	14.3	Regulation of Transcription Elongation	333
			14.4	Regulation of Translation	336
			14.5	Regulating Complex Cellular Processes	338

15 Eukaryotic and Archaeal Genome Replication and Expression	353
15.1 Why Consider Eukaryotic and Archaeal Genetics Together?	354
15.2 DNA Replication	354
15.3 Transcription	358
15.4 Translation and Protein Maturation and Localization	363
15.5 Regulation of Cellular Processes	367
16 Mechanisms of Genetic Variation	372
16.1 Mutations	372
16.2 Detection and Isolation of Mutants	378
16.3 DNA Repair	380
16.4 Creating Additional Genetic Variability	383
16.5 Transposable Elements	385
16.6 Bacterial Conjugation	387
16.7 Bacterial Transformation	393
16.8 Transduction	396
16.9 Evolution in Action: The Development of Antibiotic Resistance in Bacteria	398
17 Recombinant DNA Technology	404
17.1 Key Developments in Recombinant DNA Technology	405
Techniques & Applications 17.1	
Streptavidin-Biotin Binding and Biotechnology	410
17.2 Polymerase Chain Reaction	411
17.3 Cloning Vectors and Creating Recombinant DNA	412
Techniques & Applications 17.2	
How to Build a Microorganism	416
17.4 Construction of Genomic Libraries	417
17.5 Introducing Recombinant DNA into Host Cells	418
17.6 Expressing Foreign Genes in Host Cells	419
18 Microbial Genomics	424
18.1 Determining DNA Sequences	424
18.2 Genome Sequencing	429
18.3 Bioinformatics	431
18.4 Functional Genomics	433

18.5 Proteomics	437
18.6 Systems Biology	440
18.7 Comparative Genomics	440
18.8 Metagenomics	443

Part Five The Diversity of the Microbial World

19 Microbial Taxonomy and the Evolution of Diversity	447
19.1 Introduction to Microbial Taxonomy	448
19.2 Taxonomic Ranks	449
19.3 Exploring Microbial Taxonomy and Phylogeny	450
19.4 Phylogenetic Trees	456
19.5 Evolutionary Processes and the Concept of a Microbial Species	459
19.6 <i>Bergey's Manual of Systematic Bacteriology</i>	464
Microbial Diversity & Ecology 19.1	
"Official" Nomenclature Lists—A Letter from <i>Bergey's</i>	465
20 The Archaea	469
20.1 Overview of the Archaea	470
20.2 Phylum <i>Crenarchaeota</i>	476
20.3 Phylum <i>Euryarchaeota</i>	480
21 The Deinococci, Mollicutes, and Nonproteobacterial Gram-Negative Bacteria	489
21.1 <i>Aquificae</i> and <i>Thermotogae</i>	490
21.2 <i>Deinococcus-Thermus</i>	490
21.3 Class <i>Mollicutes</i> (Phylum <i>Tenericutes</i>)	491
21.4 Photosynthetic Bacteria	494
21.5 Phylum <i>Planctomycetes</i>	501
21.6 Phylum <i>Chlamydiae</i>	501
21.7 Phylum <i>Spirochaetes</i>	504
21.8 Phylum <i>Bacteroidetes</i>	506
21.9 Phylum <i>Verrucomicrobia</i>	507
22 The Proteobacteria	509
22.1 Class <i>Alphaproteobacteria</i>	510
22.2 Class <i>Betaproteobacteria</i>	518
22.3 Class <i>Gammaproteobacteria</i>	522
Microbial Diversity & Ecology 22.1	
Bacterial Bioluminescence	530
22.4 Class <i>Deltaproteobacteria</i>	533
22.5 Class <i>Epsilonproteobacteria</i>	538

Contents

23 Firmicutes: The Low G + C Gram-Positive Bacteria	542
23.1 Class <i>Clostridia</i>	543
23.2 Class <i>Bacilli</i>	547
24 Actinobacteria: The High G + C Gram-Positive Bacteria	555
24.1 Order <i>Actinomycetales</i>	557
24.2 Order <i>Bifidobacteriales</i>	566
25 The Protists	568
25.1 Overview of Protists	569
25.2 Supergroup <i>Excavata</i>	571
25.3 Supergroup <i>Amoebozoa</i>	573
25.4 Supergroup <i>Rhizaria</i>	574
25.5 Supergroup <i>Chromalveolata</i>	577
25.6 Supergroup <i>Archaeplastida</i>	584
26 The Fungi (Eumycota)	588
26.1 Overview of Fungal Biology	590
26.2 <i>Chytridiomycota</i>	593
26.3 <i>Zygomycota</i>	593
26.4 <i>Glomeromycota</i>	594
26.5 <i>Ascomycota</i>	595
26.6 <i>Basidiomycota</i>	598
Disease 26.1	
White-Nose Syndrome Is Decimating North American Bat Populations	599
26.7 <i>Microsporidia</i>	601
27 Viruses	604
27.1 Virus Taxonomy and Phylogeny	604
27.2 Double-Stranded DNA Viruses	606
Microbial Diversity & Ecology 27.1	
What Is a Virus?	617
27.3 Single-Stranded DNA Viruses	617
27.4 RNA Viruses: Unity Amidst Diversity	619
27.5 Double-Stranded RNA Viruses	620
27.6 Plus-Strand RNA Viruses	622
27.7 Minus-Strand RNA Viruses	624
27.8 Retroviruses	626
27.9 Reverse Transcribing DNA Viruses	628

Part Six Ecology and Symbiosis

28 Biogeochemical Cycling and Global Climate Change	632
28.1 Biogeochemical Cycling	633
28.2 Global Climate Change	642
29 Methods in Microbial Ecology	646
29.1 Culturing Techniques	647
29.2 Assessing Microbial Diversity	651
29.3 Assessing Microbial Community Activity	655
30 Microorganisms in Marine and Freshwater Ecosystems	660
30.1 Water as a Microbial Habitat	661
30.2 Microorganisms in Marine Ecosystems	662
30.3 Microorganisms in Freshwater Ecosystems	672
31 Microorganisms in Terrestrial Ecosystems	679
31.1 Soils as a Microbial Habitat	680
31.2 Microorganisms in the Soil Environment	683
31.3 Microbe-Plant Interactions	684
31.4 The Subsurface Biosphere	696
32 Microbial Interactions	699
32.1 Microbial Interactions	700
Microbial Diversity & Ecology 32.1	
<i>Wolbachia pipientis</i> : The World's Most Infectious Microbe?	701
32.2 Human-Microbe Interactions	713
Microbial Diversity & Ecology 32.2	
Do Bacteria Make People Fat?	714
32.3 Normal Microbiota of the Human Body	715

Part Seven Pathogenicity and Host Response

33 Innate Host Resistance	723
33.1 Innate Resistance Overview	724
33.2 Physical and Mechanical Barrier Defenses of Innate Resistance	725
33.3 Chemical Mediators in Innate Resistance	728
33.4 Cells, Tissues, and Organs of the Immune System	735
33.5 Phagocytosis	743
33.6 Inflammation	748

34 Adaptive Immunity	753
34.1 Overview of Adaptive Immunity	753
34.2 Antigens	755
34.3 Types of Adaptive Immunity	756
34.4 Recognition of Foreignness	757
34.5 T-Cell Biology	760
34.6 B-Cell Biology	764
34.7 Antibodies	767
Techniques & Applications 34.1	
Monoclonal Antibody Therapy	776
34.8 Action of Antibodies	777
34.9 Acquired Immune Tolerance	778
34.10 Immune Disorders	779

35 Pathogenicity and Infection	789
35.1 Pathogenicity and Infectious Disease	790
35.2 Virulence	793
35.3 Exposure and Transmission	802
Historical Highlights 35.1	
The First Indications of Person-to-Person Spread of an Infectious Disease	803

Part Eight Microbial Diseases, Detection, and Their Control

36 Clinical Microbiology and Immunology	808
36.1 Overview of the Clinical Microbiology Laboratory	808
36.2 Biosafety	809
36.3 Identification of Microorganisms from Specimens	812
36.4 Clinical Immunology	820

37 Epidemiology and Public Health Microbiology	830
37.1 Epidemiology	830
Historical Highlights 37.1	
The Birth of Public Health in the United States	831
Historical Highlights 37.2	
John Snow, the First Epidemiologist	832
37.2 Epidemiological Methods	832
Historical Highlights 37.3	
SARS: Evolution of a Virus	833

37.3 Measuring Infectious Disease Frequency	835
37.4 Patterns of Infectious Disease in a Population	836
Historical Highlights 37.4	
"Typhoid Mary"	837
37.5 Emerging and Reemerging Infectious Diseases and Pathogens	839
37.6 Health-Care-Associated Infections	841
37.7 Prevention and Control of Epidemics	843
Historical Highlights 37.5	
The First Immunizations	846
37.8 Bioterrorism Preparedness	848
Historical Highlights 37.6	
1346—The First Recorded Biological Warfare Attack	849

38 Human Diseases Caused by Viruses and Prions	854
38.1 Airborne Diseases	855
38.2 Arthropod-Borne Diseases	865
38.3 Direct Contact Diseases	865
38.4 Food-Borne and Waterborne Diseases	878
Historical Highlights 38.1	
A Brief History of Polio	881
38.5 Zoonotic Diseases	881
Disease 38.2	
Viral Hemorrhagic Fevers: A Microbial History Lesson	882
38.6 Prion Diseases	885

39 Human Diseases Caused by Bacteria	888
39.1 Airborne Diseases	888
39.2 Arthropod-Borne Diseases	898
39.3 Direct Contact Diseases	901
Disease 39.1	
A Brief History of Syphilis	909
Disease 39.2	
Biofilms	910
39.4 Food-Borne and Waterborne Diseases	915
Techniques & Applications 39.3	
Clostridial Toxins as Therapeutic Agents: Benefits of Nature's Most Toxic Proteins	919
39.5 Zoonotic Diseases	924
39.6 Opportunistic Diseases	926

Contents

40 Human Diseases Caused by Fungi and Protists	932
40.1 Pathogenic Fungi and Protists	932
40.2 Airborne Diseases	934
40.3 Arthropod-Borne Diseases	937
Disease 40.1	
A Brief History of Malaria	938
40.4 Direct Contact Diseases	944
40.5 Food-Borne and Waterborne Diseases	948
40.6 Opportunistic Diseases	952

Part Nine Applied Microbiology

41 Microbiology of Food	958
41.1 Microbial Growth and Food Spoilage	959
41.2 Controlling Food Spoilage	961
41.3 Food-Borne Disease Outbreaks	964
41.4 Detection of Food-Borne Pathogens	967
41.5 Microbiology of Fermented Foods	969
Techniques & Applications 41.1	
Chocolate: The Sweet Side of Fermentation	970
41.6 Probiotics	976

42 Biotechnology and Industrial Microbiology	979
42.1 Major Products of Industrial Microbiology	980
42.2 Biofuel Production	982
42.3 Growing Microbes in Industrial Settings	983
42.4 Microorganisms Used in Industrial Microbiology	985
42.5 Agricultural Biotechnology	990
42.6 Microbes as Products	992
43 Applied Environmental Microbiology	996
43.1 Water Purification and Sanitary Analysis	996
Techniques & Applications 43.1	
Waterborne Diseases, Water Supplies, and Slow Sand Filtration	999
43.2 Wastewater Treatment	1001
43.3 Microbial Fuel Cells	1008
43.4 Biodegradation and Bioremediation	1009

Appendix 1 A Review of the Chemistry of Biological Molecules A-1

Appendix 2 Common Metabolic Pathways A-9

Glossary G-1

Credits C-1

Index I-1