Contents

Preface xii

Chapter 1 — 1

INTRODUCTION

1.1 Microorganisms as Cells 1 1.2 Microbial Diversity 2 1.3 The Discovery of Microorganisms 3 1.4 Spontaneous Generation 6 1.5 The Germ Theory of Disease 7 1.6 The Microbial Environment 11 1.7 The Contemporary Study of Microorganisms 12 Supplementary Readings 13

Chapter 2 — 14

THE PROCARYOTIC CELL

2.1 Seeing the Very Small 14 2.2 Size and Form of Procaryotes 20 2.3 Detailed Structure of the Procaryotic Cell 21 2.4 Cell Membranes 21 2.5 Cell Wall 25 2.6 Ribosomes and Nuclear Region 33 2.7 Flagella and Motility 34 2.8 Chemotaxis in Bacteria 39 A Bit of History 42 2.9 Other Cell and Surface Structures 43 2.10 Gas Vesicles 46 2.11 Bacterial Endospores 48 2.12 Summary 51 Supplementary Readings 52

Chapter 3 — 53

THE EUCARYOTIC CELL AND EUCARYOTIC MICROORGANISMS

3.1 Membrane Systems 53 3.2 Mitochondria 54 3.3 Chloroplasts 57 3.4 Movement 58 3.5 The Nucleus, Cell Division, and Sexual Reproduction 62 3.6 Comparisons of the Procaryotic and Eucaryotic Cell 69 3.7 The Algae 70 3.8 The Fungi 74 3.9 The Slime Molds 79 3.10 The Protozoa 83 Supplementary Readings 86

Chapter 4 88

ENERGETICS

4.1 Free Energy 89 4.2 Activation Energy, Catalysis, and Enzymes 90 4.3 Oxidation-Reduction 91 4.4 Electron Carriers 93 4.5 High-Energy Phosphate Compounds and Adenosine Triphosphate (ATP) 95 4.6 Energy Release in Biological Systems 97 4.7 Fermentation 98 4.8 Respiration 103 4.9 Electron-Transport (Oxidative) Phosphorylation 105 4.10 Tricarboxylic Acid Cycle 109 4.11 The Balance Sheet of Aerobic Oxidation 111 4.12 Anaerobic Respiration 113 4.13 Summary 115 Supplementary Readings 118

Chapter 5 119

BIOSYNTHESIS AND NUTRITION

5.1 Anabolism and Catabolism 119 5.2 Nutrition and Biosynthesis 121 5.3 Hexose Metabolism 123 5.4 Pentose Metabolism 127 5.5 Organic Acid Metabolism 131 5.6 Molecular Oxygen (O_2) as a Reactant in Biochemical Processes 133 5.7 Fatty Acid Metabolism 134 5.8 Isoprenoids and Sterols 138 5.9 Hydrocarbons 141 5.10 Amino Acid Metabolism 142 5.11 Purine and Pyrimidine Metabolism 145 5.12 Porphyrin Ring 148 5.13 Bacterial Cell-Wall Synthesis 148 5.14 Control of Biosynthetic Versus Degradative Processes 151 5.15 Inorganic Nitrogen Metabolism 153 A Bit of History 156 5.16 Sulfur Metabolism 159 5.17 Phosphorus Metabolism 160 5.18 Mineral Nutrition 160 5.19 Iron Nutrition and Biochemistry 162 5.20 Organic Growth Factors 165 5.21 Transport and Nutrition 168 5.22 Summary 173 Supplementary Readings 175

Chapter 6 177

THE AUTOTROPHIC WAY OF LIFE

6.1 Photosynthesis 177 6.2 The Role of Chlorophyll in Photosynthesis 178 6.3 Electron Flow in Green-Plant Photosynthesis 180 6.4 Light Reactions in the Purple and Green Bacteria 183 A Bit of History 184 6.5 Anoxygenic Photosynthesis 188 6.6 Additional Aspects of Photosynthetic Light Reactions 189 6.7 Autotrophic CO_2 Fixation 192 6.8 Variants of the Photosynthetic Carbon Cycle 196 6.9 Ecology of Photosynthetic Organisms 198 6.10 Chemolithotrophy: Energy from the Oxidation of Inorganic Energy Sources 201 A Bit of History 201 6.11 Comparison of Autotrophs and Heterotrophs 206 6.12 Summary 209 Supplementary Readings 210

Chapter 7 211

GROWTH AND ITS CONTROL

7.1 Population Growth 211 7.2 Measuring Microbial Number and Weight 214 7.3 The Growth Cycle of Populations 215 7.4 Effect of Nutrient Concentration on Growth 217 7.5 Continuous Culture 218 7.6 Antimicrobial Agents 220 7.7 Effect of Antimicrobial Agents on Growth 222 7.8 Quantification of Antimicrobial Action 222 7.9 Growth-Factor Analogs 224 A Bit of History 227 7.10 Antibiotics 228 7.11 Germicides, Disinfectants and Antiseptics 231 7.12 Summary 233 Supplementary Readings 233

Chapter 8 235

THE MICROBE IN ITS ENVIRONMENT

8.1 Temperature 235 8.2 Water and Water Activity 247 8.3 Hydrostatic Pressure 254 8.4 Acidity and pH 255 8.5 Oxygen 258 8.6 Radiation 263 8.7 Summary 268 Supplementary Readings 269

Chapter 9 271

MACROMOLECULES: SYNTHESIS AND REGULATION

9.1 DNA Structure and Synthesis 273 9.2 RNA Polymerase and the Formation of Messenger RNA 279 9.3 Transfer RNA: Structure and Function 282 9.4 Protein Synthesis 285 9.5 Regulation of Protein Synthesis: Induction and Repression 289 A Bit of History 290 9.6 Growth and Macromolecular Synthesis 296 9.7 Cellular Differentiation and Morphogenesis 297 9.8 Practical Significance of Enzyme Regulation 300 9.9 The Energetics of Growth and Macromolecular Synthesis 302 9.10 Summary 305 Supplementary Readings 307

Chapter 10 309

VIRUSES

10.1 The Virus Particle or Virion 310 A Bit of History 313 10.2 General Features of Virus Replication 314 10.3 Viral Nucleic Acid and Protein Synthesis 317 10.4 Viral Genetics 320 10.5 Regulation of DNA Virus Reproduction 323 10.6 Regulation of RNA Viruses 331 10.7 Virus Restriction and Modification by the Host 332 10.8 Temperate Bacterial Viruses: Lysogeny 336 10.9 Viruses of Vertebrates 345 10.10 Origin and Evolution of Viruses 347 Supplementary Readings 348

Chapter 11 350

GENETICS

11.1 The Genetic Code 351 11.2 Mutants and Their Isolation 353 11.3 The Molecular Basis of Mutation 356 11.4 Mechanisms of Mutagenesis 359 11.5 Mutagenesis and Carcinogenesis: The Use of Bacterial Mutagenesis to Detect Potentially Carcinogenic Chemicals 362 11.6 Genetic Recombination 364 11.7 Genetic Transformation 365 11.8 Transduction 368 11.9 Summary 372 Supplementary Readings 372

Chapter 12 374

PLASMIDS, CONJUGATION, AND RECOMBINANT DNA

12.1 Introduction to Plasmids 374 12.2 Conjugation and Plasmid: Chromosome Interactions 379 12.3 Kinds of Plasmids and Their Biological Significance 385 A Bit of History 392 12.4 Plasmids, Recombinant DNA, and Genetic Engineering 395 12.5 An Overview of the Bacterial Genetic Map 398 12.6 Summary 401 Supplementary Readings 404

Chapter 13 406

MICROBIAL ACTIVITIES IN NATURE

13.1 Microorganisms in Nature 408 13.2 Aquatic Habitats 411 13.3 Oxygen Relationships in Aquatic Environments 412 13.4 Terrestrial Environments 415 13.5 Biogeochemical Cycles on a Global Scale 418 13.6 The Carbon Cycle 419 13.7 Methane and Methanogenesis 421 13.8 The Nitrogen Cycle 424 13.9 The Phosphorus Cycle, Algal Productivity, and Eutrophication 431 13.10 The Sulfur Cycle 434 13.11 Iron and Manganese Transformations 440 13.12 Mining Microbiology 445 13.13 Trace Element Cycles: Mercury 449 13.14 Sewage and Waste-Water Treatment 451 13.15 Pesticide Biodegradation 454 Supplementary Readings 455

Chapter 14 457

MICROBIAL SYMBIOSIS

14.1 Lichens 457 A Bit of History 460 14.2 Microbial Interactions with Higher Organisms 461 14.3 Normal Flora of the Skin 462 14.4 Normal Flora of the Oral Cavity: Dental Plaque 463 14.5 Normal Flora of the Gastrointestinal Tract 468 14.6 Normal Flora of Other Body Regions 471 14.7 Germ-Free Animals 472 14.8 Rumen Symbiosis 474 14.9 Normal Flora of Plants 478 14.10 Symbiotic Nitrogen Fixation 479 A Bit of History 480 14.11 Mycorrhizae 485 14.12 Summary 487 Supplementary Readings 487

Chapter 15 489

HOST-PARASITE RELATIONSHIPS

15.1 Entry of the Pathogen into the Host 489
15.2 Growth in Vivo 491 15.3 Exotoxins 494
15.4 Endotoxins 499 15.5 Enterotoxins 501
15.6 Virulence and Attenuation 504 15.7 Interaction of Pathogens with Phagocytic Cells 505 15.8 Intracellular Growth 509 A Bit of History 511 15.9 Inflammation 512
15.10 Clinical Stages of Infectious Disease 513
15.11 Clinical Microbiology 513 15.12 Chemotherapy 518
15.13 Summary 522 Supplementary Readings 524

Chapter 16 526

IMMUNOLOGY AND IMMUNITY

16.1 Antigens 527 16.2 Antibodies 528
16.3 Antigen-Antibody Reactions 530 16.4 Complement and Complement Fixation 534 16.5 The Mechanism of Antibody Formation 538 16.6 Cellular Immunity and Hypersensitivity 542
16.7 Antibodies and Immunity 546 16.8 Immunization for Infectious Disease 546 A Bit of History 550
16.9 Immunology in the Diagnosis of Infectious Disease 551
16.10 Summary 553 Supplementary Readings 555

Chapter 17 556

EPIDEMIOLOGY AND ENVIRONMENTAL MICROBIOLOGY

17.1 Recognition of Infection in Populations 557
17.2 Reservoirs 559 A Bit of History 560
17.3 Mechanisms of Transmission 561 17.4 Epidemics 562
17.5 Quantitative Aspects of Propagated Epidemics and the Concept of Herd Immunity 563 17.6 Evolution of Host and Parasite 567
17.7 Public Health Measures for the Control of Epidemics 569
17.8 Respiratory Infections and Airborne Transmission 572
17.9 Waterborne Disease and Water Purification 576 A Bit of History 581 17.10 Foodborne Diseases and Epidemics 586
17.11 Venereal Diseases 590 17.12 Malaria: A Disease with Two Alternate Hosts 593 17.13 Summary 595
Supplementary Readings 596

Chapter 18 598

BACTERIA TAXONOMY AND IDENTIFICATION

18.1 Bacterial Taxonomy 598 18.2 Molecular and Genetic Taxonomy 600 18.3 Bacterial Taxonomy and Phylogeny 602
18.4 The Classification of Procaryotes 603
18.5 Enrichment Cultures 604 18.6 Pure Cultures 605
18.7 Diagnostic Tests 607 18.8 Steps in the Identification of an Unknown Bacterial Culture 607 Supplementary Readings 611

Chapter 19 612

REPRESENTATIVE PROCARYOTIC GROUPS

19.1 Purple and Green (Phototrophic) Bacteria: Part 1, Bergey's Manual 612
19.2 Cyanobacteria (Blue-Green Algae) 627
19.3 Gliding Bacteria: Part 2, Bergey's Manual 633
19.4 Sheathed Bacteria: Part 3, Bergey's Manual 639
19.5 Budding and/or Appendaged Bacteria: Part 4, Bergey's Manual 643 19.6 Spirochetes: Part 5, Bergey's Manual 649 19.7 Spiral and Curved Bacteria: Part 6, Bergey's Manual 654 19.8 The Pseudomonads: Family 1, Part 7, Bergey's Manual 657 19.9 Azotobacter 661
19.10 Rhizobium-Agrobacterium Group 662 19.11 Acetic Acid Bacteria 663 19.12 Methane-Oxidizing Bacteria 664
19.13 Enteric Bacteria 670 19.14 Vibrio and Related Genera 675 19.15 The Genus Zymomonas 679
19.16 Genetic Relatedness Among Gram-Negative, Rod-Shaped Bacteria 679 19.17 Sulfate-Reducing Bacteria 680
19.18 Gram-Negative Cocci and Coccobacilli 684
19.19 Nitrifying Bacteria 685 19.20 Sulfur- and Iron-Oxidizing Chemolithotrophs 688 19.21 Methane-Producing Bacteria 691
19.22 Gram-Positive Cocci 696 19.23 Endospore-Forming Bacteria 697 19.24 Lactic Acid Bacteria 703
19.25 The Actinomycetes and Related Genera: Part 17, Bergey's Manual 707 19.26 Coryneform Bacteria 707
19.27 Propionic Acid Bacteria 710 19.28 Mycobacterium 711
19.29 Actinomycetes 715 19.30 Rickettsias 718
19.31 The Psittacosis Group: Chlamydias 720
19.32 Mycoplasmas 723 19.33 Summary: Evolution of Microbial Diversity 725 Supplementary Readings 730

Appendix 1 734

ENERGY CALCULATIONS

Appendix 2 741

THE MATHEMATICS OF GROWTH AND CHEMOSTAT OPERATION

Appendix 3 748

BIOCHEMICAL PATHWAYS

Appendix 4 767

BERGEY'S CLASSIFICATION OF BACTERIA

Appendix 5 770

MICROSCOPY

Glossary 776

Index 784

Color plates 1–8 following 242