

CONTENTS

PREFACE

xix

1 INTRODUCTION TO MICROBIAL PHYSIOLOGY

1

The *Escherichia coli* Paradigm / 1

Cell Structure / 1

 The Cell Surface / 1

Synthesis of DNA, RNA, and Protein / 7

 Metabolic and Genetic Regulation / 10

Microbial Genetics / 10

Chemical Synthesis / 12

 Chemical Composition / 12

 Energy / 13

 Oxidation–Reduction Versus Fermentation / 15

 Nitrogen Assimilation / 18

Special Topics / 18

 Endospores / 18

 Growth / 19

 Continuous Culture / 22

Factors Affecting Growth / 22

 Nutrition / 22

 Oxygen / 24

 Carbon Dioxide / 24

Extremophiles / 25
Microbial Stress Responses / 26
Summary / 26

2 MACROMOLECULAR SYNTHESIS AND PROCESSING: DNA, RNA, AND PROTEIN SYNTHESIS

27

Structure of DNA / 28
Bacterial Nucleoids / 30
REP Elements / 35
DNA Replication / 36
DNA Replication is Bidirectional and Semiconservative / 36
DNA Polymerase Functions as a Dimer / 36
Model of DNA Replication / 37
Initiation of DNA Replication / 42
Termination of DNA Replication and Chromosome Partitioning / 46
RNA Synthesis: Transcription / 47
RNA Synthesis / 47
RNA Turnover / 53
RNA Processing / 54
Protein Synthesis: Translation / 57
Transfer RNA / 58
Charging of tRNA / 62
Ribosome Structure and Synthesis / 62
Initiation of Polypeptide Synthesis / 68
Elongation / 68
Peptide Bond Formation / 71
Translocation / 71
Termination / 72
Posttranslational Processing / 73
When Nonsense Makes Sense / 74
Coupled Transcription and Translation / 74
Protein Folding and Chaperones / 74
Folding Stages / 75
Protein Folding and Chaperone Mechanisms Outside the Cytoplasm / 76
Quality Control / 76
Protein Trafficking / 77
Insertion of Integral Membrane Proteins and Export of Periplasmic Proteins / 77
Secretion of Proteins Across the Outer Membrane / 79

Protein Degradation /	83
Degradation of Abnormal Proteins /	83
Energy-Dependent Proteases /	86
Antibiotics that affect Nucleic Acid and Protein Synthesis /	88
Agents Affecting DNA Metabolism /	88
Agents Affecting Transcription /	91
Agents Affecting Translation /	92
Nucleoids /	97
DNA Replication /	98
Transcription and Translation /	98
Protein Folding, Trafficking, and Degradation /	99
Antibiotics /	100

3 BACTERIAL GENETICS: DNA EXCHANGE, RECOMBINATION, MUTAGENESIS, AND REPAIR

101

Transfer of Genetic Information in Prokaryotes /	101
Plasmids /	102
Partitioning /	102
Incompatibility /	103
Nonconjugative, Mobilizable Plasmids /	103
Resistance Plasmids /	103
Plasmids in Other Bacterial Genera /	104
Plasmid Replication /	104
Addiction Modules: Plasmid Maintenance by Host Killing: The <i>ccd</i> Genes /	108
Conjugation /	108
F Factor /	108
cis/trans complementation Test /	115
Conjugation and Pheromones in Enterococci /	116
Conjugation, Cell-Cell Signaling, and Bacterial-Induced Tumors /	117
Transformation /	118
Gram-Positive Transformation /	119
Gram-Negative Transformation /	121
Transfection and Forced Competence /	124
Transduction /	124
Recombination /	127
General Recombination /	128
Genetics of Recombination /	131
Restriction and Modification /	133

Insertion Sequences and Transposable Elements /	138
Transposon Tn10 /	140
Transposon Tn3 /	143
Conjugative Transposition /	143
Evolutionary Consideration /	144
Integrans /	145
Mutagenesis /	145
Spontaneous Mutations /	147
The Nature of Mutational Events /	147
Suppressor Mutations /	148
DNA Repair Systems /	152
Photoreactivation /	152
Nucleotide Excision Repair /	152
Transcription-Coupled Repair /	155
Methyl-Directed Mismatch Repair /	156
Very Short-Patch Mismatch Repair /	157
DNA Glycosylases and Base Excision Repair /	158
Adaptive Response to Methylating and Ethylating Agents /	159
Postreplication Daughter Strand Gap Repair /	160
SOS-Inducible Repair /	162
Replication Restart /	164
Adaptive Mutations /	166
Plasmids /	167
Transformation /	167
Conjugation /	168
Recombination /	168
Restriction Modification /	168
Transposition /	169
Mutagenesis /	169
Repair Mechanisms /	169

4 MICROBIAL PHYSIOLOGY IN THE GENOMIC ERA: A REVOLUTIONARY TALE

171

Genomic and Proteomic Tools /	171
Cloning a Genome /	171
DNA Sequencing /	172
Web Science: Internet Tools for DNA Sequence Analysis /	173
Gene Replacement /	175
Gene Arrays /	177
Proteomics /	177

Traditional Tools /	181
Mutant Hunts /	181
Transcriptional and Translational Gene Fusions (Reporter Genes) /	182
Polymerase Chain Reaction /	182
DNA Mobility Shifts (Gel Shifts and Supershifts) /	185
Finding Transcriptional Starts by Primer Extension /	186
Detecting DNA, RNA, Protein, and DNA-Binding Proteins by Southern, Northern, Western, and Southwestern Blots /	187
Two-Hybrid Analysis /	188
Summary /	192

5 REGULATION OF PROKARYOTIC GENE EXPRESSION

194

Transcriptional Control /	194
DNA-Binding Proteins /	195
The <i>lac</i> Operon: A Paradigm of Gene Expression /	197
Catabolite Control: Sensing Energy Status /	201
Class I and Class II CRP-Dependent Genes /	204
The Catabolite Repressor/Activator Protein <i>Cra</i> /	204
Catabolite Control: The Gram-Positive Paradigm /	206
The <i>gal</i> Operon: DNA Looping with a Little Help from <i>Hu</i> /	206
The Arabinose Operon: One Regulator, Two Functions /	206
Attenuation Controls /	211
Transcriptional Attenuation Mechanisms /	211
Translational Attenuation Control: The <i>pyrC</i> Strategy /	215
Membrane-Mediated Regulation: The <i>put</i> System /	216
Recombinational Regulation of Gene Expression (Flagellar Phase Variation) /	217
Translational Repression /	219
Anti- σ Regulation by Molecular Hijacking /	220
Titrating a Posttranscriptional Regulator: The <i>CsrA/CsrB</i> Carbon Storage Regulatory Team /	222
Global Control Networks /	223
Communication with the Environment: Two-Component Regulatory Systems /	223
Regulation of Nitrogen Assimilation and Nitrogen Fixation: Examples of Integrated Biochemical and Genetic Controls /	227
Phosphate Uptake: Communication Between Transport and Two-Component Regulatory Systems /	232

Quorum Sensing: How Bacteria Talk to Each Other /	234
Proteolytic Control /	235
Summary /	236

6 BACTERIOPHAGE GENETICS

239

General Characteristics of Bacteriophages /	239
T4 Phage /	245
Structure /	245
General Pattern of T4 Gene Expression /	247
T4 Genome /	250
λ Phage /	256
The Lysis-Lysogeny Decision /	256
Transcription /	259
Function of Cro Versus CI Repressor and the Structure of O_L and O_R /	259
Establishment of Repressor Synthesis /	260
Control of Integration and Excision /	262
Negative Retroregulation of <i>int</i> by <i>sib</i> /	263
λ -Phage Replication /	264
μ Phage: Transposition as a Lifestyle /	266
Φ X174 /	271
Summary /	274
General /	274
T4 Bacteriophage /	274
λ Phage /	275
ϕ X174 /	275
μ Phage /	275

7 CELL STRUCTURE AND FUNCTION

277

The Eukaryotic Nucleus /	277
Bacterial Nucleoids /	278
Nucleosomes /	282
Mitochondria /	287
Microbial Cell Surfaces /	288
Eukaryotic Cell Surfaces /	288
Prokaryotic Cell Surfaces /	289
Surface Layers of Bacteria /	290
Peptidoglycans of Bacterial Cell Walls /	290
Peptidoglycan (Murein) Hydrolases /	294
Peptidoglycan (Murein) Synthesis /	295
Teichoic Acids and Lipoteichoic Acids /	300
Outer Membranes of Gram-Negative Bacteria /	303

Lipopolysaccharide Biosynthesis	/ 308
Enterobacterial Common Antigen	/ 309
Cytoplasmic Membranes	/ 310
Permeability and Transport	/ 313
Periplasm	/ 313
Other Membranous Organelles	/ 313
Capsules	/ 315
Microbial Biofilms	/ 322
Organs of Locomotion	/ 323
Cilia and Flagella of Eukaryotes	/ 323
Bacterial (Prokaryotic) Flagella	/ 324
Chemotaxis	/ 327
Swarming Motility	/ 334
Motility in Spirochetes	/ 337
Gliding Motility	/ 339
Pili or Fimbriae	/ 340
Nucleus, Nucleosomes, and Nucleoids	/ 343
Mitochondria	/ 344
Eukaryotic Cell Surface	/ 344
Surface (S) layers	/ 344
Bacterial Cell Wall Peptidoglycan (Murein)	/ 345
Teichoic and Lipoteichoic Acids	/ 346
Outer Membrane	/ 346
Cytoplasmic Membrane	/ 346
Periplasm	/ 346
Capsules	/ 346
Biofilms	/ 346
Cilia and Flagella of Eukaryotes	/ 347
Bacterial Flagella	/ 347
Chemotaxis	/ 348
Swarming Motility	/ 348
Gliding Motility	/ 348
Motility in Spirochetes	/ 348
Pili or Fimbriae	/ 349

8 CENTRAL PATHWAYS OF CARBOHYDRATE METABOLISM

350

Alternate Pathways of Carbohydrate Metabolism	/ 350
Fructose Bisphosphate Aldolase Pathway	/ 350
Alternate Pathways of Glucose Utilization	/ 353
Entner-Doudoroff or Ketogluconate Pathway	/ 354
Phosphoketolase Pathway	/ 356
Oxidative Pentose Phosphate Cycle	/ 358

Gluconeogenesis / 360
Regulation / 360
Glycogen Synthesis / 361
Tricarboxylic Acid Cycle / 361
Glyoxylate Cycle / 365

9 ENERGY PRODUCTION AND METABOLITE TRANSPORT 368

Energy Production / 368
Substrate-Level Phosphorylation / 369
Oxidative Phosphorylation / 371
Measurement of PMF / 372
Electron Transport Systems / 373
Anaerobic Respiration / 375
Conversion of PMF to Energy / 377
Structure of F_1F_0 and the <i>atp</i> Operon / 379
Energy Yield / 380
Generating ATP in Alkalophiles / 380
Energetics of Chemolithotrophs / 380
pH Homeostasis / 381
Metabolite Transport / 382
Facilitated Diffusion / 382
Mechanosensitive Channels / 384
ATP-Binding Cassette Transporter Family / 385
Chemiosmotic-Driven Transport / 385
Establishing Ion Gradients / 386
Specific Transport Systems / 387
ATP-Linked Ion Motive Pumps / 387
The Histidine Permease / 389
Iron / 389
Phosphotransferase System / 390
Summary / 392
Energy Production / 392
Metabolite Transport / 392

10 METABOLISM OF SUBSTRATES OTHER THAN GLUCOSE 394

Utilization of Sugars Other Than Glucose / 394
Lactose / 394
Galactose / 396
Maltose / 396

Mannitol / 396

Fucose and Rhamnose / 397

Melibiose, Raffinose, Stachyose, and Guar Gum / 399

Pectin and Aldohexuronate Pathways / 400

Cellulose Degradation / 402

Starch, Glycogen, and Related Compounds / 402

Metabolism of Aromatic Compounds / 407

Pectin Utilization / 410

Cellulose Utilization / 410

Utilization of Starch, Glycogen, and Related Compounds / 411

Utilization of Aromatic Hydrocarbons / 411

11 FERMENTATION PATHWAYS

412

Fermentation Balances / 412

Yeast Fermentation / 414

Lactic Acid-Producing Fermentations / 417

Butyric Acid—and Solvent-Producing Fermentations / 423

Fermentations of the Mixed-Acid Type / 425

Propionic Acid Fermentation / 428

Acetic Acid Fermentation / 430

Fermentation Pathways / 431

Yeast Fermentation / 431

Lactic Acid Fermentation / 432

Butyric Acid and Solvent-Producing Fermentations / 432

Mixed-Acid Fermentations / 433

Propionic Acid Fermentation / 433

Acetic Acid Fermentation / 433

12 PHOTOSYNTHESIS AND INORGANIC METABOLISM

434

Characteristics and Metabolism of Autotrophs / 434

Photosynthetic Bacteria and Cyanobacteria / 434

Autotrophic CO₂ Fixation and Mechanisms of

Photosynthesis / 437

Hydrogen Bacteria / 440

Nitrifying Bacteria / 442

Sulfur Bacteria / 442

Iron Bacteria / 443

Methylootrophs / 444

Methanogens / 446

13 LIPIDS AND STEROLS

450

Lipid Composition of Microorganisms / 450

Straight-Chain Fatty Acids / 451

Branched-Chain Fatty Acids / 453

Ring-Containing Fatty Acids / 454

Alk-1-enyl Ethers (Plasmalogens) / 455

Alkyl Ethers / 455

Phospholipids (Phosphoglycerides) / 457

Glycolipids / 458

Biosynthesis of Fatty Acids / 459

Degradation of Fatty Acids / 464

Biosynthesis of Phospholipids / 465

Biosynthesis of Isoprenoids / 468

14 NITROGEN METABOLISM

475

Biological Nitrogen Fixation / 475

The Nitrogen Fixation Process / 479

Components of the Nitrogenase System / 480

Symbiotic Nitrogen Fixation / 483

Inorganic Nitrogen Metabolism / 487

Assimilation of Inorganic Nitrogen / 492

General Reactions of Amino Acids / 494

Amino Acid Decarboxylases / 494

Amino Acid Deaminases / 494

Amino Acid Transaminases (Aminotransferases) / 497

Amino Acid Racemases / 498

Role of Pyridoxal-5'-Phosphate in Enzymatic Reactions with

Amino Acids / 499

The Stickland Reaction / 500

Nitrogen Fixation / 501

Inorganic Nitrogen / 502

Urease / 502

Assimilation of Inorganic Nitrogen / 502

15 BIOSYNTHESIS AND METABOLISM OF AMINO ACIDS

503

The Glutamate or α -Ketoglutarate Family / 503

Glutamine and Glutathione Synthesis / 503

The Proline Pathway / 504

Aminolevulinate Synthesis / 504

The Arginine Pathway / 504

Polyamine Biosynthesis / 509	
The α -Ketoadipate Pathway to Lysine / 510	
The Aspartate and Pyruvate Families / 513	
Asparagine Synthesis / 513	
The Aspartate Pathway / 514	
The Bacterial Pathway to Lysine / 515	
Threonine, Isoleucine, and Methionine Formation / 516	
Isoleucine, Valine, and Leucine Biosynthesis / 518	
Regulation of the Aspartate Family / 518	
The Serine-Glycine Family / 520	
Aminolevulinate and the Pathway to Tetrapyrroles / 523	
The Aromatic Amino Acid Pathway / 523	
Phenylalanine, Tyrosine, and Tryptophan / 523	
The Common Aromatic Amino Acid Pathway / 525	
Pathways to Tyrosine and Phenylalanine / 526	
<i>p</i> -Aminobenzoate and Folate Biosynthesis / 531	
Enterobactin Biosynthesis / 533	
The Pathway to Ubiquinone / 534	
Menaquinone (Vitamin K) Biosynthesis / 534	
Biosynthesis of Nicotinamide Adenine Dinucleotide (NAD) / 534	
Histidine Biosynthesis / 539	
Amino Acids / 541	
Glutamate (α -Ketoglutarate) Family / 541	
Aspartate and Pyruvate Families / 542	
Serine-Glycine Family / 543	
Aromatic Amino Acid Family / 543	
Histidine / 544	

16 PURINES AND PYRIMIDINES

545

Biosynthesis of Purines / 545	
Biosynthesis of Pyrimidines / 550	
Interconversion of Nucleotides, Nucleosides, and Free Bases:	
Salvage Pathways / 554	
Regulation of Purine and Pyrimidine Biosynthesis / 555	
Purines and Pyrimidines / 559	
Riboflavin Biosynthesis / 560	
Thiamine Biosynthesis / 560	

17 BACTERIAL CELL DIVISION

561

Cell Division in Gram-Negative Rods / 561	
Cell Division in Gram-Positive Cocci / 570	

Cell Division in Gram-Positive Bacilli /	575
General Reviews /	578
Cell Division in Gram-Negative Rods /	579
Cell Division in Gram-Positive Cocci /	580
Cell Division in Gram-Positive Bacilli /	581

18 MICROBIAL STRESS RESPONSES

582

Osmotic Stress and Osmoregulation /	582
High Osmolality /	583
Low Osmolality /	584
Osmotic Control of Gene Expression /	585
Aerobic to Anaerobic Transitions /	587
Formate Nitrate Regulation /	589
Nitrate Response /	589
ArcAB System /	591
Oxidative Stress /	592
Regulation of the Oxidative Stress Response /	594
pH Stress and Acid Tolerance /	596
Thermal Stress and the Heat Shock Response /	597
Nutrient Stress and the Starvation—Stress Response /	601
Starvation—Stress Response /	601
Stringent Control /	602
Extremophiles /	605
Summary /	608
Osmotic Stress and Osmoregulation /	608
Aerobic to Anaerobic Transitions /	609
Oxidative Stress /	609
pH Stress and Acid Tolerance /	610
Thermal Stress and the Heat Shock Response /	610
Nutrient Stress and the Starvation Stress Response /	611
Stringent Control /	611
Extremophiles /	611

19 BACTERIAL DIFFERENTIATION

612

<i>Bacillus</i> Endospore Formation /	612
Life Cycle of <i>Bacillus</i> /	613
Stages of Sporulation /	614
Physiological and Genetic Aspects of Sporulation /	616
Sporulation Genes /	616
Initiation /	617

Transition from Stage II to Stage III /	619
Forespore Development /	620
Final Stages of Sporulation /	621
Spore Cortex Synthesis /	622
Spore Coat Protein Synthesis /	622
Activation, Germination, and Outgrowth of Bacterial Endospores /	623
Activation /	624
Germination /	624
Outgrowth /	627
Myxobacterial Developmental Cycle /	628
Life Cycle of Myxobacteria /	628
Aggregation and Fruiting Body Formation /	629
Genetics of <i>Myxococcus xanthus</i> Development /	632
<i>Caulobacter</i> Differentiation /	637
Life Cycle of <i>Caulobacter crescentus</i> /	637
The Stalk, the Holdfast, and the Flagellum: Structure, Genetics, and Regulation /	638
Regulation and Checkpoints of the Cell Cycle of <i>C. crescentus</i> /	642
Endospore Formation /	644
Germination and Outgrowth of Endospores /	645
Myxobacterial Developmental Cycle /	646
<i>Caulobacter</i> Differentiation /	647

20 HOST-PARASITE INTERACTIONS

648

Overview of Host-Parasite Relationships /	648
Structures and Functions Involved in Host-Parasite Interactions /	650
Adherence/Colonization /	650
Virulence Factor Secretion Systems /	653
Exotoxins /	658
Quorum Sensing /	664
Paradigms of Bacterial Pathogenesis /	669
Enteropathogenic <i>Escherichia coli</i> /	669
<i>Salmonella Enterica</i> Serovars /	669
<i>Listeria Monocytogenes</i> /	670
<i>Chlamydia</i> spp /	672
Overview /	672
Adherence/Colonization /	672
Virulence Factor Secretion Systems /	673

Exotoxins / 673

Quorum Sensing / 674

Paradigms of Bacterial Pathogenesis / 675

INDEX

676