

## Table of Contents

- 1 What Is Life? p. 1
- 1.1 Hierarchical Organization of Knowledge p. 1
- 1.2 General Characteristics of Living Systems p. 5
- 1.3 Artificial Life p. 7
- 1.4 Biological Information, Information Processing and Signalling p. 17
- 1.5 Origin of Life p. 23
- 1.6 Emergence, Intelligence and Consciousness p. 47
- 2 What Are the Molecules of Life? p. 61
- 2.1 Nucleic Acids, DNA, RNA p. 61
- 2.1.1 Chemical Bonds and Bond Energies p. 65
- 2.2 Generalized Ester Bonds p. 65
- 2.3 Directionality of Chemical Bonds p. 69
- 2.4 Types of Inter-Atomic Interactions p. 80
- 2.4.1 Ionic Interactions p. 80
- 2.6 Amphipatic Molecules in Water Environments p. 101
- 2.4.2 Covalent Bonds p. 83
- 2.4.3 Free Radicals p. 86
- 2.4.4 Van der Waals Forces p. 86
- 2.5 The Hydrogen Bonds and Hydrophobic Interactions p. 92
- 2.5.1 Polysaccharides p. 100
- 2.6.1 Fatty Acids p. 103
- 2.6.2 Lipids p. 105
- 2.7 Structure of Proteins p. 105
- 2.7.4 Electrophoresis of Proteins p. 124
- 2.7.1 The Polypeptide Chains p. 110
- 2.7.2 Proteins p. 112
- 2.7.3 The Process of Protein Folding p. 120
- 2.7.5 Protein Interaction with Environment p. 125
- 2.7.6 Electron Transfer in Proteins p. 126
- 2.8.3 Fluorescence in Biomolecules p. 136
- 2.8 Structure of Nucleic Acids p. 127
- 2.8.1 The Electrostatic Potential of DNA p. 133
- 2.8.2 DNA: Information and Damage p. 134
- 3 What Is a Biological Cell? p. 151
- 3.1 Cytoplasm p. 151
- 3.1.1 Osmotic Pressure of Cells p. 152
- 3.1.2 Osmotic Work p. 153
- 3.2 Cytoskeleton p. 154
- 3.2.1 The Cytoskeleton p. 154
- 3.2.2 Biopolymers of the Cytoskeleton p. 156
- 3.2.3 Tubulin p. 157
- 3.2.4 Microtubules p. 161
- 3.2.5 Actin Filaments p. 166
- 3.2.6 Actin Binding Proteins p. 170

- 3.2.7 Intermediate Filaments p. 171
- 3.3 Tubulin Isotype Homology Modelling p. 173
- 3.3.1 Solvent Accessible Surface Area p. 177
- 3.3.2 Net Charge p. 177
- 3.3.3 Dipole Moment Estimation p. 178
- 3.3.4 Human Repeats and Dipole-Dipole Interactions p. 178
- 3.3.5 Motor Proteins p. 185
- 3.4 Anisotropic Elastic Properties of Microtubules p. 188
- 3.5 Centrioles, Basal Bodies, Cilia and Flagella p. 197
- 3.6 Networks and Meshworks of Protein Filaments, Stress Fibers and Tensegrity p. 201
- 3.7 Cell Nucleus and Chromosomes p. 203
- 3.7.1 Nuclear Chromatin, Chromosomes, Nuclear Lamina p. 203
- 3.7.2 Chromatin/Chromosomes p. 204
- 3.8 Mitochondria and Proton Pumps: Energy Generation and Utilization in the Cell p. 206
- 3.8.1 Cell Energetics: Chloroplasts and Mitochondria p. 206
- 3.8.2 The Cell as a Machine p. 208
- 3.8.3 Active Transport p. 209
- 3.8.4 Ion Channels and Ion Pumps p. 210
- 3.9 Cytochrome Oxidase Enzymes p. 212
- 3.9.1 Introduction p. 212
- 3.9.2 The Biochemical Structure and Function of the Cytochromes p. 213
- 3.9.3 A Simplified Model Calculation p. 218
- 3.9.4 A Proposed Mechanism p. 221
- 3.10 Membranes and Vesicles p. 224
- 3.11 Motor Proteins and Their Role in Cellular Processes p. 233
- 3.11.1 Myosin p. 236
- 3.11.2 Kinesin Family p. 239
- 3.11.3 Ncd Dimer Structure p. 241
- 3.11.4 Dynein p. 242
- 3.11.5 Myosin V p. 243
- 3.11.6 Myosin VI p. 249
- 3.12 Directed Binding as a Model of Kinesin Walk p. 250
- 3.12.1 Chemical Reaction-based Models p. 256
- 3.12.2 Mechanically Based Models p. 258
- 3.12.3 Models with Alternating Chemical and Mechanical Transformations p. 259
- 3.13 Other Structures p. 268
- 3.14 Large Polar Molecules p. 269
- 3.14.1 Bioferroelectricity p. 269
- 4 What Are Life Processes? p. 307
- 4.1 Oxidative Phosphorylation p. 307
- 4.1.1 The Biochemical Energy Currency- The ATP Molecule p. 308
- 4.2 Diffusion Processes p. 313
- 4.2.1 Translational Diffusion p. 314
- 4.3.2 Bioenergetics: The Davydov Model p. 329
- 4.2.2 Diffusional Flow Across Membranes p. 318

- 4.3 Proton Transport and Bioenergetics p. 329
- 4.3.1 Proton Transport p. 329
- 4.4 Electronic and Ionic Conductivities of Microtubules and Actin Filaments p. 335
  - 4.4.1 The Neuron p. 336
  - 4.4.2 The Cytoskeleton p. 340
  - 4.4.3 Overview of Biological Conductivity p. 342
  - 4.4.4 Intrinsic Electronic Conductivity of Microtubules p. 345
  - 4.4.5 Actin Filaments Support Non-linear Ionic Waves p. 368
  - 4.4.6 Long-range Spatio-temporal Ionic Waves along Microtubules p. 373
  - 4.4.7 Dendritic Cytoskeleton Information Processing Model p. 378
  - 4.4.8 The Inter-relation Between the Neural Cytoskeleton and the Membrane p. 381
  - 4.4.9 Relationship to Cognitive Functions p. 382
  - 4.4.10 The Potential for Bioelectronic Applications and Neuromorphic Computing p. 385
  - 4.4.11 Discussion p. 387
- 4.5 Mechanisms of Exciton Energy Transfer in Scheibe Aggregates p. 389
  - 4.5.1 The Exciton Model p. 390
  - 4.5.2 Exciton Domain Size p. 393
  - 4.5.3 Random Walk Model p. 395
  - 4.5.4 Phonons p. 397
  - 4.5.5 Exciton-Phonon Coupling p. 398
  - 4.5.6 The Role of Non-linearity p. 399
  - 4.5.7 Conclusions p. 400
- 4.6 Conformational Transitions in Proteins p. 403
  - 4.6.1 The Protein-glass Model p. 406
  - 4.6.2 The Protein-machine Model p. 407
- 4.7 Vesicle Transport and Molecular Motors p. 409
  - 4.7.1 Chemo-Chemical Machines p. 409
  - 4.7.2 Biological Machines as Biased Maxwell's Demons p. 413
  - 4.7.3 Pumps and Motors as Chemo-chemical Machines p. 415
- 4.8 Muscle Contraction p. 420
  - 4.8.1 Biophysics of Muscles p. 420
  - 4.8.2 Biophysical Mechanisms, Contractile Proteins p. 424
- 4.9 Subcellular Structure Formation p. 428
  - 4.9.1 Aspects of Polymerization of Microtubules p. 428
  - 4.9.2 Simple Models of Microtubule Assembly p. 430
  - 4.9.3 Developing a Stochastic Model p. 435
  - 4.9.4 A Stochastic Model Without Rescues p. 436
  - 4.9.5 The Average Picture; Master Equations p. 438
  - 4.9.6 Stochastic Models with Rescues p. 440
  - 4.9.7 A Model with a Finite Collapse Velocity p. 442
  - 4.9.8 Conditions for Stationary Bell-Shaped Distributions p. 443
  - 4.9.9 Coherence Effects p. 445
  - 4.9.10 Summary and Conclusions p. 447
  - 4.9.11 Assembly of Actin Filaments p. 448
- 4.10 Cell Division p. 453

- 4.10.1 Cell Division p. 453
- Glossary p. 481
- Index p. 499