

# Contents

|                                                               |           |
|---------------------------------------------------------------|-----------|
| Preface                                                       | xi        |
| <b>1 Introduction</b>                                         | <b>1</b>  |
| Exercises                                                     | 6         |
| Further reading                                               | 6         |
| <b>2 Chemical Binding</b>                                     | <b>7</b>  |
| 2.1 Quantum Mechanics                                         | 7         |
| 2.2 Pauli Exclusion Principle                                 | 9         |
| 2.3 Ionization Energy, Electron Affinity and Chemical Binding | 10        |
| 2.4 Electronegativity and Strong Bonds                        | 15        |
| 2.5 Secondary Bonds                                           | 21        |
| Exercises                                                     | 22        |
| Further reading                                               | 22        |
| <b>3 Energies, Forces and Bonds</b>                           | <b>23</b> |
| 3.1 Interatomic Potentials for Strong Bonds                   | 23        |
| 3.2 Interatomic Potentials for Weak Bonds                     | 29        |
| 3.3 Non-central Forces                                        | 32        |
| 3.4 Bond Energies                                             | 33        |
| 3.5 Spring Constants                                          | 39        |
| Exercises                                                     | 40        |
| Further reading                                               | 41        |
| <b>4 Rates of Reaction</b>                                    | <b>43</b> |
| 4.1 Free Energy                                               | 43        |
| 4.2 Internal Energy                                           | 45        |
| 4.3 Thermodynamics and Statistical Mechanics                  | 46        |
| 4.4 Reaction Kinetics                                         | 55        |
| 4.5 Water, Acids, Bases and Aqueous Reactions                 | 59        |
| 4.6 Radiation Energy                                          | 65        |
| Exercises                                                     | 67        |
| Further reading                                               | 68        |

|           |                                           |            |
|-----------|-------------------------------------------|------------|
| <b>5</b>  | <b>Transport Processes</b>                | <b>69</b>  |
| 5.1       | Diffusion                                 | 69         |
| 5.2       | Viscosity                                 | 76         |
| 5.3       | Thermal Conduction                        | 80         |
|           | Exercises                                 | 81         |
|           | Further reading                           | 81         |
| <b>6</b>  | <b>Some Techniques and Methods</b>        | <b>83</b>  |
| 6.1       | X-Ray Diffraction and Molecular Structure | 83         |
| 6.2       | Nuclear Magnetic Resonance                | 93         |
| 6.3       | Scanning Tunnelling Microscopy            | 98         |
| 6.4       | Atomic Force Microscopy                   | 102        |
| 6.5       | Optical Tweezers                          | 103        |
| 6.6       | Patch Clamping                            | 108        |
| 6.7       | Molecular Dynamics                        | 112        |
| 6.8       | Potential Energy Contour Tracing          | 115        |
|           | Exercises                                 | 118        |
|           | Further reading                           | 119        |
| <b>7</b>  | <b>Biological Polymers</b>                | <b>123</b> |
| 7.1       | Nucleic Acids                             | 124        |
| 7.2       | Nucleic Acid Conformation: DNA            | 129        |
| 7.3       | Nucleic Acid Conformation: RNA            | 132        |
| 7.4       | Proteins                                  | 134        |
| 7.5       | Protein Folding                           | 151        |
|           | Exercises                                 | 157        |
|           | Further reading                           | 158        |
| <b>8</b>  | <b>Biological Membranes</b>               | <b>161</b> |
| 8.1       | Historical Background                     | 161        |
| 8.2       | Membrane Chemistry and Structure          | 166        |
| 8.3       | Membrane Physics                          | 174        |
|           | Exercises                                 | 184        |
|           | Further reading                           | 185        |
| <b>9</b>  | <b>Biological Energy</b>                  | <b>187</b> |
| 9.1       | Energy Consumption                        | 187        |
| 9.2       | Respiration                               | 188        |
| 9.3       | Photosynthesis                            | 190        |
| 9.4       | ATP Synthesis                             | 199        |
|           | Exercises                                 | 206        |
|           | Further reading                           | 207        |
| <b>10</b> | <b>Movement of Organisms</b>              | <b>209</b> |
| 10.1      | Bacterial Motion                          | 209        |
| 10.2      | Chemical Memory in Primitive Organisms    | 218        |

|           |                                           |            |
|-----------|-------------------------------------------|------------|
| <b>5</b>  | <b>Transport Processes</b>                | <b>69</b>  |
| 5.1       | Diffusion                                 | 69         |
| 5.2       | Viscosity                                 | 76         |
| 5.3       | Thermal Conduction                        | 80         |
|           | Exercises                                 | 81         |
|           | Further reading                           | 81         |
| <b>6</b>  | <b>Some Techniques and Methods</b>        | <b>83</b>  |
| 6.1       | X-Ray Diffraction and Molecular Structure | 83         |
| 6.2       | Nuclear Magnetic Resonance                | 93         |
| 6.3       | Scanning Tunnelling Microscopy            | 98         |
| 6.4       | Atomic Force Microscopy                   | 102        |
| 6.5       | Optical Tweezers                          | 103        |
| 6.6       | Patch Clamping                            | 108        |
| 6.7       | Molecular Dynamics                        | 112        |
| 6.8       | Potential Energy Contour Tracing          | 115        |
|           | Exercises                                 | 118        |
|           | Further reading                           | 119        |
| <b>7</b>  | <b>Biological Polymers</b>                | <b>123</b> |
| 7.1       | Nucleic Acids                             | 124        |
| 7.2       | Nucleic Acid Conformation: DNA            | 129        |
| 7.3       | Nucleic Acid Conformation: RNA            | 132        |
| 7.4       | Proteins                                  | 134        |
| 7.5       | Protein Folding                           | 151        |
|           | Exercises                                 | 157        |
|           | Further reading                           | 158        |
| <b>8</b>  | <b>Biological Membranes</b>               | <b>161</b> |
| 8.1       | Historical Background                     | 161        |
| 8.2       | Membrane Chemistry and Structure          | 166        |
| 8.3       | Membrane Physics                          | 174        |
|           | Exercises                                 | 184        |
|           | Further reading                           | 185        |
| <b>9</b>  | <b>Biological Energy</b>                  | <b>187</b> |
| 9.1       | Energy Consumption                        | 187        |
| 9.2       | Respiration                               | 188        |
| 9.3       | Photosynthesis                            | 190        |
| 9.4       | ATP Synthesis                             | 199        |
|           | Exercises                                 | 206        |
|           | Further reading                           | 207        |
| <b>10</b> | <b>Movement of Organisms</b>              | <b>209</b> |
| 10.1      | Bacterial Motion                          | 209        |
| 10.2      | Chemical Memory in Primitive Organisms    | 218        |

|           |                                                  |            |
|-----------|--------------------------------------------------|------------|
| 10.3      | Muscular Movement                                | 220        |
| 10.4      | Human Performance                                | 233        |
|           | Exercises                                        | 235        |
|           | Further reading                                  | 235        |
| <b>11</b> | <b>Excitable Membranes</b>                       | <b>237</b> |
| 11.1      | Diffusion and Mobility of Ions                   | 237        |
| 11.2      | Resting Potential                                | 240        |
|           | Exercises                                        | 246        |
|           | Further reading                                  | 246        |
| <b>12</b> | <b>Nerve Signals</b>                             | <b>249</b> |
| 12.1      | Passive Response                                 | 249        |
| 12.2      | Nerve Impulses (Action Potentials)               | 256        |
| 12.3      | The Nervous System                               | 268        |
|           | Exercises                                        | 275        |
|           | Further reading                                  | 275        |
| <b>13</b> | <b>Memory</b>                                    | <b>277</b> |
| 13.1      | Hebbian Learning                                 | 277        |
| 13.2      | Neural Networks                                  | 281        |
| 13.3      | Auto-association                                 | 288        |
|           | Exercises                                        | 293        |
|           | Further reading                                  | 294        |
| <b>14</b> | <b>Control of Movement</b>                       | <b>297</b> |
| 14.1      | The Primacy of Movement                          | 297        |
| 14.2      | Ballistic Control in a Simplified Visual System  | 299        |
| 14.3      | More Sophisticated Modes of Control              | 304        |
| 14.4      | The Heterogeneous Structure of Muscle Fibres     | 305        |
| 14.5      | Central Pattern Generators                       | 307        |
| 14.6      | Conditioned Reflexes                             | 311        |
| 14.7      | Volition and Free Will                           | 314        |
| 14.8      | What Purpose Does Consciousness Serve?           | 320        |
| 14.9      | Passive versus Active in Mental Processing       | 325        |
| 14.10     | The Relevant Anatomy and Physiology              | 328        |
| 14.11     | Intelligence and Creativity                      | 335        |
| 14.12     | A Final Word                                     | 338        |
|           | Exercises                                        | 339        |
|           | Further reading                                  | 339        |
|           | <b>Appendix A: Elements of Quantum Mechanics</b> | <b>343</b> |
| A.1       | Quantization of Energy                           | 343        |
| A.2       | Atomic Structure                                 | 345        |
| A.3       | The Wave Equation                                | 347        |
| A.4       | Quantum Mechanical Tunnelling                    | 350        |

|                                                    |            |
|----------------------------------------------------|------------|
| Exercises                                          | 352        |
| Further reading                                    | 352        |
| <b>Appendix B: The Hydrogen Atom</b>               | <b>353</b> |
| B.1 The Hamiltonian                                | 353        |
| B.2 The Hydrogen Atom                              | 353        |
| B.3 Solution of the $\Phi$ Equation                | 356        |
| B.4 Solution of the $\Theta$ Equation              | 357        |
| B.5 Solution of the $R$ Equation                   | 358        |
| B.6 Quantum Numbers and Energy Levels              | 360        |
| B.7 Wave Functions                                 | 360        |
| Exercises                                          | 364        |
| Further reading                                    | 364        |
| <b>Appendix C: Thermal Motion</b>                  | <b>365</b> |
| C.1 Ideal Gases                                    | 365        |
| C.2 Liquids                                        | 369        |
| Exercises                                          | 371        |
| Further reading                                    | 371        |
| <b>Appendix D: Probability Distributions</b>       | <b>373</b> |
| D.1 Bernoulli Trials and the Binomial Distribution | 373        |
| D.2 The Poisson Approximation                      | 373        |
| D.3 The Normal, or Gaussian, Distribution          | 375        |
| Further reading                                    | 376        |
| <b>Appendix E: Differential Equations</b>          | <b>377</b> |
| Further reading                                    | 379        |
| Name Index                                         | 381        |
| Subject Index                                      | 385        |