

|          |  |          |
|----------|--|----------|
| <b>1</b> | <b>Introduction to Modern Physics</b>                      | <b>1</b> |
| 1.1      | Fundamental Physical Constants                             | 2        |
| 1.2      | Derived Physical Constants and Relationships               | 4        |
| 1.3      | Milestones in Modern Physics and Medical Physics           | 6        |
| 1.4      | Physical Quantities and Units                              | 7        |
| 1.5      | Classification of Forces in Nature                         | 11       |
| 1.6      | Classification of Fundamental Particles                    | 13       |
| 1.7      | Classification of Radiation                                | 14       |
| 1.8      | Classification of Ionizing Radiation                       | 16       |
| 1.9      | Classification of Directly Ionizing Radiation              | 17       |
| 1.10     | Classification of Indirectly Ionizing Photon Radiation     | 19       |
| 1.11     | Radiation Quantities and Units                             | 20       |
| 1.12     | Dose Distribution in Water for Various Radiation Beams     | 21       |
| 1.13     | Basic Definitions for Atomic Structure                     | 24       |
| 1.14     | Basic Definitions for Nuclear Structure                    | 27       |
| 1.15     | Nuclear Binding Energies                                   | 28       |
| 1.16     | Nuclear Models   | 31       |
| 1.17     | Physics of Small Dimensions and Large Velocities           | 32       |
| 1.18     | Planck Energy Quantization                                 | 34       |
| 1.19     | Quantization of Electromagnetic Radiation                  | 40       |
| 1.20     | Special Theory of Relativity                               | 43       |
| 1.21     | Important Relativistic Relations                           | 50       |
| 1.22     | Particle-Wave Duality                                      | 69       |
| 1.23     | Matter Waves   | 80       |
| 1.24     | Uncertainty Principle                                      | 87       |
| 1.25     | Complementarity Principle                                  | 88       |
| 1.26     | Emission of Electrons from Material Surface: Work Function | 89       |
| 1.27     | Thermionic Emission  | 92       |
| 1.28     | Tunneling  | 98       |
| 1.29     | Maxwell Equations  | 107      |
| 1.30     | Poynting Theorem and Poynting Vector                       | 110      |
| 1.31     | Normal Probability Distribution                            | 112      |

|          |  |     |
|----------|--|-----|
| <b>2</b> | <b>Coulomb Scattering</b>  | 117 |
| 2.1      | General Aspects of Coulomb Scattering  | 118 |
| 2.2      | Geiger-Marsden Experiment  | 122 |
| 2.3      | Rutherford Scattering  | 128 |
| 2.4      | Cross Sections for Rutherford Scattering   | 145 |
| 2.5      | Mott Scattering  | 152 |
| 2.6      | General Aspects of Elastic Scattering of Charged Particles                           | 165 |
| 2.7      | Molière Multiple Elastic Scattering  | 171 |
| <b>3</b> | <b>Rutherford–Bohr Atomic Model</b>  | 177 |
| 3.1      | Bohr Model of Hydrogen Atom  | 178 |
| 3.2      | Multi-electron Atoms   | 208 |
| 3.3      | Experimental Confirmation of the Bohr Atomic Model                                   | 213 |
| 3.4      | Schrödinger Equation for Hydrogen Atom   | 222 |
| <b>4</b> | <b>Production of X Rays</b>  | 225 |
| 4.1      | X-Ray Line Spectra   | 226 |
| 4.2      | Emission of Radiation by Accelerated Charged Particle<br>(Bremsstrahlung Production) | 242 |
| 4.3      | Synchrotron Radiation  | 256 |
| 4.4      | Čerenkov Radiation   | 258 |
| <b>5</b> | <b>Two-Particle Collisions</b>   | 267 |
| 5.1      | Collisions of Two Particles: General Aspects   | 268 |
| 5.2      | Nuclear Reactions  | 272 |
| 5.3      | Two-Particle Elastic Scattering: Energy Transfer                                     | 281 |
| <b>6</b> | <b>Interaction of Charged Particles with Matter</b>                                  | 299 |
| 6.1      | General Aspects of Energy Transfer from Charged Particle to<br>Medium                | 300 |
| 6.2      | General Aspects of Stopping Power  | 303 |
| 6.3      | Radiation Stopping Power   | 306 |
| 6.4      | Collision (Electronic) Stopping Power for Heavy Charged<br>Particles                 | 309 |
| 6.5      | Collision Stopping Power for Light Charged Particles                                 | 335 |
| 6.6      | Total Mass Stopping Power  | 343 |
| 6.7      | Radiation Yield  | 350 |
| 6.8      | Range of Charged Particles   | 356 |
| 6.9      | Mean Stopping Power  | 363 |
| 6.10     | Restricted Collision Stopping Power  | 367 |
| 6.11     | Bremsstrahlung Targets   | 376 |
| <b>7</b> | <b>Interaction of Photons with Matter</b>  | 387 |
| 7.1      | General Aspects of Photon Interactions with Absorbers                                | 388 |
| 7.2      | Thomson Scattering   | 402 |
| 7.3      | Incoherent Scattering (Compton Effect)   | 408 |
| 7.4      | Incoherent (Rayleigh) Scattering   | 455 |
| 7.5      | Photoelectric Effect   | 465 |

|           |  |            |
|-----------|--|------------|
| 7.6       | Pair Production . . . . .  | 483        |
| 7.7       | Photonuclear Reactions . . . . .   | 499        |
| <b>8</b>  | <b>Energy Transfer and Energy Absorption in Photon Interaction with Matter . . . . .</b> | <b>515</b> |
| 8.1       | Macroscopic Attenuation Coefficient . . . . .  | 516        |
| 8.2       | Energy Transfer from Photons to Charged Particles in Absorber . . . . .                  | 520        |
| 8.3       | Energy Transfer and Energy Absorption . . . . .  | 532        |
| 8.4       | Coefficients of Compounds and Mixtures . . . . .   | 548        |
| 8.5       | Effects Following Photon Interactions with Absorber . . . . .                            | 553        |
| 8.6       | Summary of Photon Interactions with Absorbers . . . . .                                  | 557        |
| 8.7       | Sample Calculations . . . . .  | 567        |
| <b>9</b>  | <b>Interaction of Neutrons with Matter . . . . .</b>                                     | <b>581</b> |
| 9.1       | General Aspects of Neutron Interactions with Absorbers . . . . .                         | 582        |
| 9.2       | Neutron Interactions with Nuclei of the Absorber . . . . .                               | 589        |
| 9.3       | Neutron Kerma . . . . .  | 601        |
| 9.4       | Neutron Kerma Factor . . . . .   | 605        |
| 9.5       | Neutron Dose Deposition in Tissue . . . . .  | 611        |
| 9.6       | Neutron Beams in Medicine . . . . .  | 621        |
| <b>10</b> | <b>Kinetics of Radioactive Decay . . . . .</b>   | <b>637</b> |
| 10.1      | General Aspects of Radioactivity . . . . .   | 638        |
| 10.2      | Decay of Radioactive Parent into a Stable Daughter . . . . .                             | 640        |
| 10.3      | Radioactive Series Decay . . . . .   | 646        |
| 10.4      | General Form of Daughter Activity . . . . .  | 663        |
| 10.5      | Equilibria in Parent-Daughter Activities . . . . .                                       | 666        |
| 10.6      | Bateman Equations for Radioactive Decay Chain . . . . .                                  | 671        |
| 10.7      | Mixture of Two or More Independently Decaying Radionuclides in a Sample . . . . .        | 682        |
| 10.8      | Branching Decay and Branching Fraction . . . . .   | 685        |
| <b>11</b> | <b>Modes of Radioactive Decay . . . . .</b>  | <b>693</b> |
| 11.1      | Introduction to Radioactive Decay Processes . . . . .                                    | 694        |
| 11.2      | Alpha Decay . . . . .  | 696        |
| 11.3      | Beta Decay . . . . .   | 703        |
| 11.4      | Beta Minus Decay . . . . .   | 708        |
| 11.5      | Beta Plus Decay . . . . .  | 717        |
| 11.6      | Electron Capture . . . . .   | 727        |
| 11.7      | Gamma Decay . . . . .  | 737        |
| 11.8      | Internal Conversion . . . . .  | 741        |
| 11.9      | Spontaneous Fission . . . . .  | 746        |
| 11.10     | Proton Emission Decay . . . . .  | 748        |
| 11.11     | Neutron Emission Decay . . . . .   | 755        |
| 11.12     | Chart of Nuclides . . . . .  | 759        |
| 11.13     | Summary of Radioactive Decay Modes . . . . .   | 773        |

|   |  |      |
|---|--|------|
| <b>12</b>   | <b>Production of Radionuclides</b>   | 787  |
| 12.1  | Origin of Radioactive Elements (Radionuclides)                                       | 788  |
| 12.2  | Naturally Occurring Radionuclides  | 795  |
| 12.3  | Man-Made (Artificial) Radionuclides  | 798  |
| 12.4  | Radionuclides in the Environment   | 801  |
| 12.5  | General Aspects of Nuclear Activation  | 805  |
| 12.6  | Nuclear Activation with Neutrons   | 809  |
| 12.7  | Nuclear Fission Induced by Neutron Bombardment                                       | 890  |
| 12.8  | Nuclear Chain Reaction   | 901  |
| 12.9  | Production of Radionuclides with Radionuclide Generator                              | 914  |
| 12.10   | Nuclear Activation with Protons and Heavier Charged Particles                        | 931  |
| <b>13</b>   | <b>Waveguide Theory</b>  | 941  |
| 13.1  | Microwave Propagation in Uniform Waveguide   | 942  |
| 13.2  | Boundary Conditions  | 945  |
| 13.3  | Differential Wave Equation   | 950  |
| 13.4  | Electric and Magnetic Fields in Uniform Waveguides                                   | 970  |
| 13.5  | General Conditions for Particle Acceleration   | 976  |
| 13.6  | Dispersion Relationship  | 980  |
| 13.7  | Transverse Magnetic $TM_{01}$ Mode   | 999  |
| 13.8  | Acceleration Waveguide Compared to Transmission Waveguide                            | 1008 |
| 13.9  | Relationship Between Velocity of Energy Flow and Group Velocity in Uniform Waveguide | 1014 |
| 13.10   | Disk-Loaded Waveguide  | 1023 |
| 13.11   | Capture Condition  | 1028 |
| <b>14</b>   | <b>Particle Accelerators in Medicine</b>   | 1041 |
| 14.1  | Basic Characteristics of Particle Accelerators                                       | 1042 |
| 14.2  | Practical Use of X Rays  | 1045 |
| 14.3  | Practical Considerations in Production of X Rays                                     | 1048 |
| 14.4  | Traditional Sources of X Rays  | 1051 |
| 14.5  | Circular Accelerators  | 1061 |
| 14.6  | Clinical Linear Accelerator  | 1075 |
| <b>Appendix A Main Attributes of Nuclides Presented in This Book</b>                      |  | 1101 |
| <b>Appendix B Roman Letter Symbols</b>  |  | 1107 |
| <b>Appendix C Greek Letter Symbols</b>  |  | 1117 |
| <b>Appendix D Electronic Databases of Interest in Nuclear Physics and Medical Physics</b> |  | 1121 |
| <b>Bibliography</b>   |  | 1127 |
| <b>Index</b>  |  | 1129 |