
Contents

1	Introduction to Modern Physics	1
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

2 Coulomb Scattering	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
3 Rutherford–Bohr Atomic Model	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
4 Production of X Rays	225
4.1 X-Ray Line Spectra	226
4.2 Emission of Radiation by Accelerated Charged Particle (Bremsstrahlung Production)	242
4.3 Synchrotron Radiation	256
4.4 Čerenkov Radiation	258
5 Two-Particle Collisions	267
5.1 Collisions of Two Particles: General Aspects	268
5.2 Nuclear Reactions	272
5.3 Two-Particle Elastic Scattering: Energy Transfer	281
6 Interaction of Charged Particles with Matter	299
6.1 General Aspects of Energy Transfer from Charged Particle to 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 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
7 Interaction of Photons with Matter	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
8 Energy Transfer and Energy Absorption in Photon Interaction with Matter	515
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
9 Interaction of Neutrons with Matter	581
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
10 Kinetics of Radioactive Decay	637
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
11 Modes of Radioactive Decay	693
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

12 Production of Radionuclides	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
13 Waveguide Theory	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
14 Particle Accelerators in Medicine	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
Appendix A Main Attributes of Nuclides Presented in This Book	1101
Appendix B Roman Letter Symbols	1107
Appendix C Greek Letter Symbols	1117
Appendix D Electronic Databases of Interest in Nuclear Physics and Medical Physics	1121
Bibliography	1127
Index	1129