Contents

PART 1 Introduction

Chapter 1 Brief Discussion of Nuclear Properties

1–1 Objectives of studying nuclear physics 3
1–2 Nomenclature 4
1–3 The nuclear radius 5
1–4 Nuclear mass and binding energy 9
1–5 Angular momentum 11
1–6 Parity and symmetry 12
1–7 Magnetic dipole moment 15
1–8 Electric quadrupole moment 16
1–9 Nuclear-disintegration processes 19
1–10 Chart of Nuclides and domains of instabilities 20
1–11 Nuclear reactions 23
1–12 Energy levels 25
1–13 Mirror nuclei 26

PART 2 The Nuclear Two-Body Problem

Chapter 2 The Deuteron

2–1 Introduction 31
2–2 The deuteron; experimental data 32
2–3 Simple theory of the deuteron 36
2–4 Normalization of the deuteron wave function; root-mean-square radius 40
2–5 Spin dependence of nuclear forces 42
2–6 Tensor forces 44

Chapter 3 Nucleon-Nucleon Scattering

3–1 Introduction 48
3–2 Scattering cross sections 49
3–3 Experimental data on low-energy neutron-proton scattering . 51
3–4 Partial wave analysis of n-p scattering 54

3–5 Determination of the phase shift δ_0 58
3–6 Singlet and triplet potentials 61
3–7 Effective-range theory 65
3–8 Example of proton-proton scattering at low energies . . . 68
3–9 Theory of proton-proton scattering at low energies . . . 70
3–10 High-energy nucleon-nucleon scattering 73
3–11 Meson theory of nuclear forces 79

PART 3 Properties of Stable Nuclei, Nuclear Models

Chapter 4 Masses and Relative Abundances of Atomic Species

4–1 Introduction 89
4–2 Deflection-type mass spectrographs and spectrometers . . 89
4–3 The doublet method of mass spectroscopy 96
4–4 The mass synchrometer 98
4–5 Atomic masses from nuclear-reaction and disintegration data 100
4–6 The semiempirical mass formula 102
4–7 Relative abundances of atomic species 107

Chapter 5 Nuclear Moments

5–1 Hyperfine structure of atomic spectra 110
5–2 Effect of an external magnetic field on the hyperfine structure 113
5–3 Molecular excitations and determination of I from molecular band spectra 116
5–4 Nuclear parameters as determined by microwave spectroscopy methods 120
5–5 Molecular-beam resonance methods 123
5–6 Molecular-beam experiments on hydrogen 126
5–7 Nuclear magnetic resonances in liquids and solids . . . 129
5–8 Measurement of the magnetic moment of the neutron . . 133
5–9 Results of measurements of nuclear moments 136

Chapter 6 Nuclear Models

6–1 Review of the atomic shell model and predicted ground-state angular momenta 139
6–2 Single-particle model of the nucleus 143
6–3 Magic numbers; spin-orbit coupling 149
6–4 Predicted angular momenta of nuclear ground states . . 153
6–5 Excited states and the shell model 156
6–6 Magnetic moments and the shell model; Schmidt lines . . 158

6–7 Symmetry; isospin 161
6–8 Single particle orbits in a distorted well 166
6–9 Collective motion; rotational states 170
6–10 Vibrational states 172

PART 4 Nuclear-Disintegration Studies

Chapter 7 Stopping and Detecting Nuclear Radiations

7–1 Stopping power and range for charged nuclear particles . . 181
7–2 Stopping power and range for electrons 188
7–3 Absorption of gamma rays 191
7–4 Stopping of neutrons 197
7–5 Gas-filled counters 200
7–6 The solid-state counter 206
7–7 The scintillation counter 209
7–8 Nuclear emulsions 213
7–9 Neutron detection 215
7–10 Special detectors for high-energy radiation 217

Chapter 8 Radioactivity

8–1 Natural radioactivity 223
8–2 The radioactive decay law 225
8–3 Artificially produced radionuclides 227
8–4 Units of radiation 229
8–5 Statistics of counting 232
8–6 Effects of limited time resolution of counting equipment . . 237

Chapter 9 Gamma Transitions

9–1 Introduction 239
9–2 Measurements of gamma-ray energies 240
9–3 Measurements of lifetimes of excited states 247
9–4 Multipole moments 251
9–5 Theoretical predictions of decay constants 252
9–6 Selection rules 255
9–7 Angular correlation 257
9–8 Estimates of transition rates and comparison with experiment 259
9–9 Internal conversion 266

Chapter 10 Alpha Decay

10–1 Stability of heavy nuclei against breakup 274
10–2 Measurement of alpha-particle energies 276

10–3 Experimental decay constants; the Geiger-Nuttal law . . 279
10–4 Barrier penetration 282
10–5 Barrier penetration as applied to alpha decay 286
10–6 Reduced widths of alpha-unstable states 291
10–7 Nuclear energy levels as deduced from alpha-decay data . 295

Chapter 11 ***Beta Decay***

11–1 Introduction 302
11–2 Instruments of beta spectroscopy 306
11–3 Simple theory of beta decay 313
11–4 Kurie plots; example of beta spectra 319
11–5 Comparative half-lives 323
11–6 Allowed and forbidden transitions; selection rules . . . 326
11–7 Electron capture 328
11–8 Parity violation in beta decay 330
11–9 Neutrinos 333
11–10 Measurement of the neutrino helicity 336

PART 5 Nuclear-Reaction Studies, Nuclear Energy, Elementary Particles

Chapter 12 ***Accelerators and Sources of Atomic Particles***

12–1 Ion sources 345
12–2 Direct-current accelerators 348
12–3 The cyclotron 352
12–4 The linear accelerator (Linac) 356
12–5 The betatron 359
12–6 The electron synchrotron 362
12–7 The proton synchrotron 366
12–8 Neutron sources 369

Chapter 13 ***Nuclear Reactions***

13–1 Introduction 373
13–2 Reaction dynamics; the Q-equation 376
13–3 Charged-particle reaction spectroscopy 379
13–4 Neutron spectroscopy 388
13–5 Theories of nuclear reactions 390
13–6 Partial-wave analysis of reaction cross sections . . . 393
13–7 Compound-nucleus formation and breakup 396
13–8 Resonance scattering and reactions 400
13–9 Nuclear resonance spectroscopy 405

13–10 The optical model 409
13–11 Theory of stripping reactions 415
13–12 Stripping reactions and the shell model 421
13–13 Coulomb excitation 425
13–14 Photonuclear reactions 431

Chapter 14 ***Nuclear Energy***

14–1 The fission process 439
14–2 Neutrons released in the fission process; cross sections . . 443
14–3 The fission reactor operating with natural uranium as fuel . 447
14–4 Fusion; thermonuclear energy 451
14–5 Prospect of controlled fusion energy 453

Chapter 15 ***Elementary Particles***

15–1 Introduction 461
15–2 Experimental techniques 462
15–3 Physical properties of the elementary particles . . . 470
15–4 Associated production and strangeness 471
15–5 Fundamental particles and interactions 474
15–6 Baryon spectroscopy 476
15–7 Meson spectroscopy 481
15–8 The eightfold way 484

Appendix 1 ***Brief Review of the Mechanics of Atomic Particles***

A1–1 The mks system of units 489
A1–2 Relativistic particle dynamics 490
A1–3 Motion of charged particles in magnetic fields . . . 491
A1–4 Wave-particle duality 493
A1–5 The uncertainty principle 494
A1–6 Wave functions 494
A1–7 Operators 495
A1–8 The Schrödinger equation 498
A1–9 Spherical coordinates and spherical harmonic functions . 499
A1–10 Parity and orbital angular momentum 501
A1–11 The two-body problem in wave mechanics 503

Appendix 2 ***Ion-Beam Focusing and Dispersion in Electric and Magnetic Fields***

A2–1 Equations of motion 505
A2–2 Sector fields 509
A2–3 Dispersion 510

Appendix 3 ***Barrier Penetration*** 512

Appendix 4 ***Time-Dependent Perturbation Theory***

A4–1 General first-order theory 516
A4–2 Transitions to the continuum 518
A4–3 Reaction and scattering cross sections 520

Appendix 5 ***Matrix Diagonalization*** 522

Appendix 6 ***Table of Nuclides*** 524

Name Index 569

Index 573