

SUBATOMIC PHYSICS

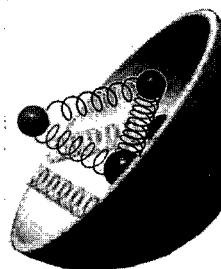
Third Edition



Ernest M Henley

Alejandro García

University of Washington, USA



 **World Scientific**

NEW JERSEY • LONDON • SINGAPORE • BEIJING • SHANGHAI • HONG KONG • TAIPEI • CHENNAI

Contents

<i>Dedication</i>	v
<i>Acknowledgments</i>	vii
<i>Preface to the First Edition</i>	ix
<i>Preface to the Third Edition</i>	xi
<i>General Bibliography</i>	xiii
1 Background and Language	1
1.1 Orders of Magnitude	1
1.2 Units	3
1.3 Special Relativity, Feynman Diagrams	4
1.4 References	8
I Tools	11
2 Accelerators	13
2.1 Why Accelerators?	13
2.2 Cross Sections and Luminosity	16
2.3 Electrostatic Generators (Van de Graaff)	18
2.4 Linear Accelerators (Linacs)	20
2.5 Beam Optics	22
2.6 Synchrotrons	24
2.7 Laboratory and Center-of-Momentum Frames	29
2.8 Colliding Beams	31
2.9 Superconducting Linacs	31
2.10 Beam Storage and Cooling	32
2.11 References	34

3	Passage of Radiation Through Matter	39
3.1	Concepts	39
3.2	Heavy Charged Particles	41
3.3	Photons	45
3.4	Electrons	46
3.5	Nuclear Interactions	49
3.6	References	50
4	Detectors	53
4.1	Scintillation Counters	53
4.2	Statistical Aspects	56
4.3	Semiconductor Detectors	59
4.4	Bubble Chambers	62
4.5	Spark Chambers	64
4.6	Wire Chambers	65
4.7	Drift Chambers	66
4.8	Time Projection Chambers	67
4.9	Čerenkov Counters	68
4.10	Calorimeters	69
4.11	Counter Electronics	70
4.12	Electronics: Logic	72
4.13	References	73
II	Particles and Nuclei	77
5	The Subatomic Zoo	79
5.1	Mass and Spin. Fermions and Bosons	79
5.2	Electric Charge and Magnetic Dipole Moment	84
5.3	Mass Measurements	87
5.4	A First Glance at the Subatomic Zoo	92
5.5	Gauge Bosons	94
5.6	Leptons	97
5.7	Decays	98
5.8	Mesons	103
5.9	Baryon Ground States	105
5.10	Particles and Antiparticles	108
5.11	Quarks, Gluons, and Intermediate Bosons	112
5.12	Excited States and Resonances	118
5.13	Excited States of Baryons	122
5.14	References	128

6	Structure of Subatomic Particles	135
6.1	The Approach: Elastic Scattering	135
6.2	Rutherford and Mott Scattering	136
6.3	Form Factors	140
6.4	The Charge Distribution of Spherical Nuclei	143
6.5	Leptons Are Point Particles	147
6.6	Nucleon Elastic Form Factors	153
6.7	The Charge Radii of the Pion and Kaon	160
6.8	Inelastic Electron and Muon Scattering	161
6.9	Deep Inelastic Electron Scattering	164
6.10	Quark-Parton Model for Deep Inelastic Scattering	166
6.11	More Details on Scattering and Structure	172
6.12	References	189
III	Symmetries and Conservation Laws	195
7	Additive Conservation Laws	197
7.1	Conserved Quantities and Symmetries	197
7.2	The Electric Charge	203
7.3	The Baryon Number	206
7.4	Lepton and Lepton Flavor Number	208
7.5	Strangeness Flavor	211
7.6	Additive Quantum Numbers of Quarks	214
7.7	References	216
8	Angular Momentum and Isospin	221
8.1	Invariance Under Spatial Rotation	221
8.2	Symmetry Breaking by a Magnetic Field	223
8.3	Charge Independence of Hadronic Forces	224
8.4	The Nucleon Isospin	225
8.5	Isospin Invariance	226
8.6	Isospin of Particles	228
8.7	Isospin in Nuclei	232
8.8	References	235
9	P, C, CP, and T	239
9.1	The Parity Operation	239
9.2	The Intrinsic Parities of Subatomic Particles	243
9.3	Conservation and Breakdown of Parity	247
9.4	Charge Conjugation	252
9.5	Time Reversal	256
9.6	The Two-State Problem	260

9.7	The Neutral Kaons	263
9.8	The Fall of CP Invariance	268
9.9	References	271

IV Interactions 279

10	The Electromagnetic Interaction	281
10.1	The Golden Rule	281
10.2	Phase Space	286
10.3	The Classical Electromagnetic Interaction	289
10.4	Photon Emission	292
10.5	Multipole Radiation	299
10.6	Electromagnetic Scattering of Leptons	303
10.7	Vector Mesons as Mediators of the Photon-Hadron Interaction	307
10.8	Colliding Beams	311
10.9	Electron-Positron Collisions and Quarks	314
10.10	The Photon-Hadron Interaction: Real and Spacelike Photons	317
10.11	Magnetic Monopoles	323
10.12	References	324
11	The Weak Interaction	331
11.1	The Continuous Beta Spectrum	331
11.2	Beta Decay Lifetimes	335
11.3	The Current-Current Interaction of the Standard Model	337
11.4	A Variety of Weak Processes	342
11.5	The Muon Decay	346
11.6	The Weak Current of Leptons	348
11.7	Chirality versus Helicity	353
11.8	The Weak Coupling Constant G_F	354
11.9	Weak Decays of Quarks and the CKM Matrix	355
11.10	Weak Currents in Nuclear Physics	356
11.11	Inverse Beta Decay: Reines and Cowan's Detection of Neutrinos	361
11.12	Massive Neutrinos	363
11.13	Majorana versus Dirac Neutrinos	365
11.14	The Weak Current of Hadrons at High Energies	366
11.15	References	375
12	Introduction to Gauge Theories	383
12.1	Introduction	383
12.2	Potentials in Quantum Mechanics—The Aharonov-Bohm Effect	386
12.3	Gauge Invariance for Non-Abelian Fields	388
12.4	The Higgs Mechanism; Spontaneous Symmetry Breaking	393

12.5	General References	401
13	The Electroweak Theory of the Standard Model	403
13.1	Introduction	403
13.2	The Gauge Bosons and Weak Isospin	404
13.3	The Electroweak Interaction	408
13.4	Tests of the Standard Model	414
13.5	References	418
14	Strong Interactions	421
14.1	Range and Strength of the Low-Energy Strong Interactions	422
14.2	The Pion–Nucleon Interaction—Survey	425
14.3	The Form of the Pion–Nucleon Interaction	430
14.4	The Yukawa Theory of Nuclear Forces	432
14.5	Low-Energy Nucleon–Nucleon Force	434
14.6	Meson Theory of the Nucleon–Nucleon Force	442
14.7	Strong Processes at High Energies	445
14.8	The Standard Model, Quantum Chromodynamics	451
14.9	QCD at Low Energies	456
14.10	Grand Unified Theories, Supersymmetry, String Theories	458
14.11	References	460
V	Models	469
15	Quark Models of Mesons and Baryons	471
15.1	Introduction	471
15.2	Quarks as Building Blocks of Hadrons	472
15.3	Hunting the Quark	474
15.4	Mesons as Bound Quark States	475
15.5	Baryons as Bound Quark States	478
15.6	The Hadron Masses	480
15.7	QCD and Quark Models of the Hadrons	483
15.8	Heavy Mesons: Charmonium, Upsilon,	491
15.9	Outlook and Problems	493
15.10	References	494
16	Liquid Drop Model, Fermi Gas Model, Heavy Ions	501
16.1	The Liquid Drop Model	501
16.2	The Fermi Gas Model	506
16.3	Heavy Ion Reactions	508
16.4	Relativistic Heavy Ion Collisions	511
16.5	References	515

17 The Shell Model	521
17.1 The Magic Numbers	522
17.2 The Closed Shells	524
17.3 The Spin-Orbit Interaction	529
17.4 The Single-Particle Shell Model	531
17.5 Generalization of the Single-Particle Model	533
17.6 Isobaric Analog Resonances	535
17.7 Nuclei Far From the Valley of Stability	537
17.8 References	538
18 Collective Model	543
18.1 Nuclear Deformations	544
18.2 Rotational Spectra of Spinless Nuclei	547
18.3 Rotational Families	551
18.4 One-Particle Motion in Deformed Nuclei (Nilsson Model)	554
18.5 Vibrational States in Spherical Nuclei	558
18.6 The Interacting Boson Model	562
18.7 Highly Excited States; Giant Resonances	564
18.8 Nuclear Models—Concluding Remarks	567
18.9 References	570
19 Nuclear and Particle Astrophysics	579
19.1 The Beginning of the Universe	579
19.2 Primordial Nucleosynthesis	585
19.3 Stellar Energy and Nucleosynthesis	586
19.4 Stellar Collapse and Neutron Stars	592
19.5 Cosmic Rays	596
19.6 Neutrino Astronomy and Cosmology	601
19.7 Leptogenesis as Basis for Baryon Excess	602
19.8 References	603
<i>Index</i>	609