
Contents

<i>Preface</i>	xi
<i>Notes</i>	xiii
1 Basic concepts	1
1.1 History	1
1.1.1 The origins of nuclear physics	1
1.1.2 The emergence of particle physics: hadrons and quarks	6
1.1.3 The standard model of particle physics	9
1.2 Relativity and antiparticles	11
1.3 Space-time symmetries and conservation laws	13
1.3.1 Parity	14
1.3.2 Charge conjugation	16
1.3.3 Time reversal	17
1.4 Interactions and Feynman diagrams	20
1.4.1 Interactions	20
1.4.2 Feynman diagrams	21
1.5 Particle exchange: forces and potentials	24
1.5.1 Range of forces	24
1.5.2 The Yukawa potential	25
1.6 Observable quantities: cross-sections and decay rates	26
1.6.1 Amplitudes	27
1.6.2 Cross-sections	29
1.6.3 The basic scattering formulas	31
1.6.4 Unstable states	33
1.7 Units	36
Problems 1	37
2 Nuclear phenomenology	41
2.1 Mass spectroscopy	43
2.1.1 Deflection spectrometers	43
2.1.2 Kinematic analysis	45
2.1.3 Penning trap measurements	46
2.2 Nuclear shapes and sizes	51
2.2.1 Charge distribution	52
2.2.2 Matter distribution	56
2.3 Semi-empirical mass formula: the liquid drop model	59
2.3.1 Binding energies	59
2.3.2 Semi-empirical mass formula	60
2.4 Nuclear instability	64

2.5 Decay chains	67	4.4.4 Čerenkov counters and transition radiation	170
2.6 β decay phenomenology	69	4.4.5 Calorimeters	173
2.6.1 Odd-mass nuclei	70	4.5 Detector Systems	176
2.6.2 Even-mass nuclei	71	Problems 4	182
2.7 Fission	72		
2.8 γ decays	76		
2.9 Nuclear reactions	76		
Problems 2	81		
3 Particle phenomenology	83	5 Quark dynamics: the strong interaction	185
3.1 Leptons	83	5.1 Colour	185
3.1.1 Lepton multiplets and lepton numbers	83	5.2 Quantum chromodynamics (QCD)	187
3.1.2 Universal lepton interactions; the number of neutrinos	86	5.2.1 The strong coupling constant	190
3.1.3 Neutrinos	88	5.2.2 Screening, antiscreening and asymptotic freedom	193
3.1.4 Neutrino mixing and oscillations	90	5.3 New forms of matter	194
3.1.5 Oscillation experiments	93	5.3.1 Exotic hadrons	194
3.1.6 Neutrino masses and mixing angles	101	5.3.2 The quark-gluon plasma	201
3.1.7 Lepton numbers revisited	103	5.4 Jets and gluons	204
3.2 Quarks	104	5.4.1 Colour counting	205
3.2.1 Evidence for quarks	104	5.5 Deep inelastic scattering and nucleon structure	207
3.2.2 Quark generations and quark numbers	106	5.5.1 Scaling	207
3.3 Hadrons	109	5.5.2 The quark-parton model	210
3.3.1 Flavour independence and charge multiplets	109	5.5.3 Scaling violations and parton distributions	211
3.3.2 The simple quark model	113	5.5.4 Inelastic neutrino scattering	215
3.3.3 Hadron decays and lifetimes	117	5.6 Other processes	217
3.3.4 Hadron magnetic moments and masses	119	5.6.1 Jets	219
3.3.5 Heavy quarkonia	126	5.6.2 Lepton pair production	221
3.3.6 Allowed and exotic quantum numbers	133	5.7 Current and constituent quarks	224
Problems 3	135	Problems 5	226
4 Experimental methods	139	6 Weak interactions and electroweak unification	229
4.1 Overview	139	6.1 Charged and neutral currents	229
4.2 Accelerators and beams	142	6.2 Charged current reactions	231
4.2.1 DC accelerators	142	6.2.1 W^\pm-lepton interactions	232
4.2.2 AC accelerators	143	6.2.2 Lepton-quark symmetry and mixing	234
4.2.3 Neutral and unstable particle beams	150	6.2.3 W-boson decays	238
4.3 Particle interactions with matter	152	6.2.4 Charged current selection rules	239
4.3.1 Short-range interactions with nuclei	153	6.3 The third generation	242
4.3.2 Ionisation energy losses	154	6.3.1 More quark mixing	243
4.3.3 Radiation energy losses	157	6.3.2 Properties of the top quark	246
4.3.4 Interactions of photons in matter	158	6.4 Neutral currents and the unified theory	247
4.3.5 Ranges and interaction lengths	159	6.4.1 Electroweak unification	247
4.4 Particle detectors	160	6.4.2 The Z^0 vertices and electroweak reactions	250
4.4.1 Gaseous ionisation detectors	162	6.5 Gauge invariance and the Higgs boson	252
4.4.2 Scintillation counters	167	6.5.1 Unification and the gauge principle	253
4.4.3 Semiconductor detectors	169	6.5.2 Particle masses and the Higgs field	255
		6.5.3 Properties of the Higgs boson	257
		6.5.4 Discovery of the Higgs boson	259
		Problems 6	266

7 Symmetry breaking in the weak interaction	271	9.2 Fusion	357
7.1 P violation, C violation, and CP conservation	271	9.2.1 Coulomb barrier	357
7.1.1 Muon decay symmetries	273	9.2.2 Fusion reaction rates	358
7.1.2 Parity violation in electroweak processes	275	9.2.3 Nucleosynthesis and stellar evolution	361
7.2 Spin structure of the weak interactions	277	9.2.4 Fusion reactors	366
7.2.1 Left-handed neutrinos and right-handed antineutrinos	277	9.3 Nuclear weapons	371
7.2.2 Particles with mass: chirality	279	9.3.1 Fission devices	371
7.3 Neutral kaons: particle–antiparticle mixing and CP violation	281	9.3.2 Fission/fusion devices	374
7.3.1 CP invariance and neutral kaons	281	9.4 Biomedical applications	377
7.3.2 CP violation in K_L^0 decay	283	9.4.1 Radiation and living matter	377
7.3.3 Flavour oscillations and CPT invariance	285	9.4.2 Radiation therapy	380
7.4 CP violation and flavour oscillations in B decays	289	9.4.3 Medical imaging using ionising radiation	385
7.4.1 Direct CP violation in decay rates	290	9.4.4 Magnetic resonance imaging	390
7.4.2 $B^0 - \bar{B}^0$ mixing	291	9.5 Further applications	395
7.4.3 CP violation in interference	295	9.5.1 Computing and data analysis	395
7.5 CP violation in the standard model	299	9.5.2 Archaeology and geophysics	396
Problems 7	302	9.5.3 Accelerators and detectors	397
8 Models and theories of nuclear physics	305	9.5.4 Industrial applications	398
8.1 The nucleon–nucleon potential	305	Problems 9	398
8.2 Fermi gas model	308	10 Some outstanding questions and future prospects	401
8.3 Shell model	310	10.1 Overview	401
8.3.1 Shell structure of atoms	310	10.2 Hadrons and nuclei	402
8.3.2 Nuclear shell structure and magic numbers	312	10.2.1 Hadron structure and the nuclear environment	402
8.3.3 Spins, parities, and magnetic dipole moments	315	10.2.2 Nuclear structure	405
8.3.4 Excited states	318	10.3 Unification schemes	407
8.4 Nonspherical nuclei	319	10.3.1 Grand unification	407
8.4.1 Electric quadrupole moments	319	10.3.2 Supersymmetry	412
8.4.2 Collective model	322	10.3.3 Strings and things	417
8.5 Summary of nuclear structure models	323	10.4 The nature of the neutrino	418
8.6 α decay	324	10.4.1 Neutrinoless double beta decay	420
8.7 β decay	327	10.5 Particle astrophysics	426
8.7.1 $V - A$ theory	327	10.5.1 Neutrino astrophysics	427
8.7.2 Electron and positron momentum distributions	329	10.5.2 Cosmology and dark matter	432
8.7.3 Selection rules	330	10.5.3 Matter–antimatter asymmetry	438
8.7.4 Applications of Fermi theory	332	10.5.4 Axions and the strong CP problem	441
8.8 γ decay	337	A Some results in quantum mechanics	445
8.8.1 Selection rules	337	A.1 Barrier penetration	445
8.8.2 Transition rates	339	A.2 Density of states	447
Problems 8	340	A.3 Perturbation theory and the Second Golden Rule	449
9 Applications of nuclear and particle physics	343	A.4 Isospin formalism	452
9.1 Fission	343	A.4.1 Isospin operators and quark states	452
9.1.1 Induced fission and chain reactions	344	A.4.2 Hadron states	454
9.1.2 Thermal fission reactors	348	Problems A	456
9.1.3 Radioactive waste	352		
9.1.4 Power from ADS systems	354		

B	Relativistic kinematics	457
B.1	Lorentz transformations and four-vectors	457
B.2	Frames of reference	459
B.3	Invariants	461
	Problems B	463
C	Rutherford scattering	465
C.1	Classical physics	465
C.2	Quantum mechanics	467
	Problems C	469
D	Gauge theories	471
D.1	Gauge invariance and the standard model	471
D.1.1	Electromagnetism and the gauge principle	471
D.1.2	The standard model	471
D.2	Particle masses and the Higgs field	474
	Problems D	478
		481
E	Short answers to selected problems	483
<i>References</i>		487
<i>Index</i>		491
<i>Inside Rear Cover: Table of constants and conversion factors</i>		