

# Contents

<i>Preface</i>	<i>page xi</i>
<b>1 Quarks and leptons</b>	<b>1</b>
1.1 Preamble	1
1.2 The Standard Model of particle physics	7
1.3 Particle classification: fermions and bosons	12
1.4 Particles and antiparticles	13
1.5 Free particle wave equations	16
1.6 Helicity states: helicity conservation	19
1.7 Lepton flavours	20
1.8 Quark flavours	22
1.9 The cosmic connection	26
Problems	33
<b>2 Interactions and fields</b>	<b>35</b>
2.1 Classical and quantum pictures of interactions	35
2.2 The Yukawa theory of quantum exchange	36
2.3 The boson propagator	37
2.4 Feynman diagrams	38
2.5 Electromagnetic interactions	40
2.6 Renormalisation and gauge invariance	42
2.7 Strong interactions	43
2.8 Weak and electroweak interactions	46
2.9 Gravitational interactions	51
2.10 The interaction cross-section	51
2.11 Decays and resonances	55
Problems	61

<b>3 Invariance principles and conservation laws</b>	<b>63</b>
3.1 Translation and rotation operators	63
3.2 The parity operation	65
3.3 Pion spin and parity	66
3.4 Parity of particles and antiparticles	69
3.5 Tests of parity conservation	72
3.6 Charge conjugation invariance	73
3.7 Charge conservation and gauge invariance	75
3.8 Baryon and lepton conservation	79
3.9 <i>CPT</i> invariance	81
3.10 <i>CP</i> violation and <i>T</i> violation	81
3.11 Neutron electric dipole moment	83
3.12 Isospin symmetry	87
3.13 Isospin in the two-nucleon and pion–nucleon systems	88
3.14 Isospin, strangeness and hypercharge	91
Problems	93
<b>4 Quarks in hadrons</b>	<b>95</b>
4.1 Charm and beauty; the heavy quarkonium states	95
4.2 Comparison of quarkonium and positronium levels	102
4.3 The baryon decuplet	109
4.4 Quark spin and colour	114
4.5 The baryon octet	115
4.6 Quark–antiquark combinations: the light pseudoscalar mesons	118
4.7 The light vector mesons	121
4.8 Other tests of the quark model	123
4.9 Mass relations and hyperfine interactions	126
4.10 Electromagnetic mass differences and isospin symmetry	129
4.11 Magnetic moments of baryons	130
4.12 Mesons built of light and heavy quarks	132
4.13 The top quark	134
Problems	139
<b>5 Lepton and quark scattering</b>	<b>140</b>
5.1 The process $e^+e^- \rightarrow \mu^+\mu^-$	140
5.2 $e^+e^-$ annihilation to hadrons	144
5.3 Electron–muon scattering, $e^-\mu^+ \rightarrow e^-\mu^+$	147
5.4 Neutrino–electron scattering, $\nu_e e \rightarrow \nu_e e$	150
5.5 Elastic lepton–nucleon scattering	154
5.6 Deep inelastic scattering and partons	155
5.7 Deep inelastic scattering and quarks	159

Experimental results on quark distributions in the nucleon	162
Sum rules	166
Summary	168
Problems	168
<b>Quark interactions and QCD</b>	<b>171</b>
The colour quantum number	171
The QCD potential at short distances	172
The QCD potential at large distances: the string model	178
Gluon jets in $e^+e^-$ annihilation	180
Running couplings in QED and QCD	181
Evolution of structure functions in deep inelastic scattering	186
Gluonium and the quark-gluon plasma	190
Problems	192
<b>Weak interactions</b>	<b>194</b>
Classification	194
Lepton universality	195
Nuclear $\beta$ -decay: Fermi theory	197
Inverse $\beta$ -decay: neutrino interactions	201
Parity nonconservation in $\beta$ -decay	202
Helicity of the neutrino	205
The $V - A$ interaction	206
Conservation of weak currents	209
The weak boson and Fermi couplings	210
Pion and muon decay	210
Neutral weak currents	213
Observation of $W^\pm$ and $Z^0$ bosons in $p\bar{p}$ collisions	215
$Z^0$ production at $e^+e^-$ colliders	220
Weak decays of quarks. The GIM model and the CKM matrix	221
Neutral $K$ mesons	226
$CP$ violation in the neutral kaon system	232
Cosmological $CP$ violation	237
$D^0-\bar{D}^0$ and $B^0-\bar{B}^0$ mixing	238
Problems	239
<b>8 Electroweak interactions and the Standard Model</b>	<b>242</b>
Introduction	242
Divergences in the weak interactions	243
Introduction of neutral currents	245
The Weinberg-Salam model	246

8.5	Intermediate boson masses	248
8.6	Electroweak couplings of leptons and quarks	249
8.7	Neutrino scattering via $Z$ exchange	250
8.8	Asymmetries in the scattering of polarised electrons by deuterons	253
8.9	Observations on the $Z$ resonance	255
8.10	Fits to the Standard Model and radiative corrections	260
8.11	$W$ pair production	262
8.12	Spontaneous symmetry breaking and the Higgs mechanism	263
8.13	Higgs production and detection	271
	Problems	274
<b>9</b>	<b>Physics beyond the Standard Model</b>	<b>276</b>
9.1	Supersymmetry	277
9.2	Grand unified theories: the SU(5) GUT	278
9.3	Unification energy and weak mixing angle	280
9.4	Supersymmetric SU(5)	282
9.5	Proton decay	282
9.6	Neutrino mass: Dirac and Majorana neutrinos	284
9.7	Neutrino oscillations	287
9.8	Magnetic monopoles	299
9.9	Superstrings	300
	Problems	301
<b>10</b>	<b>Particle physics and cosmology</b>	<b>303</b>
10.1	Hubble's law and the expanding universe	303
10.2	Friedmann equation	304
10.3	Cosmic microwave radiation: the hot Big Bang	307
10.4	Radiation and matter eras	311
10.5	Nucleosynthesis in the Big Bang	313
10.6	Baryon–antibaryon asymmetry	317
10.7	Dark matter	319
10.8	Inflation	326
10.9	Neutrino astronomy: SN 1987A	330
	Problems	336
<b>11</b>	<b>Experimental methods</b>	<b>338</b>
11.1	Accelerators	338
11.2	Colliding-beam accelerators	343
11.3	Accelerator complexes	346
11.4	Secondary particle separators	346
11.5	Interaction of charged particles and radiation with matter	349

11.6 Detectors of single charged particles	355
11.7 Shower detectors and calorimeters	368
Problems	375
<i>Appendix A Table of elementary particles</i>	377
<i>Appendix B Milestones in particle physics</i>	379
<i>Appendix C Clebsch–Gordan coefficients and d-functions</i>	386
<i>Appendix D Spherical harmonics, d-functions and Clebsch–Gordan coefficients</i>	393
<i>Appendix E Relativistic normalisation of cross-sections and decay rates</i>	396
<i>Glossary</i>	398
<i>Answers to problems</i>	408
<i>Bibliography</i>	412
<i>References</i>	418
<i>Index</i>	421