

Contents

<i>Preface</i>	page xiii
<i>Acknowledgements</i>	xv
1 Introduction	1
1.1 The Standard Model of particle physics	1
1.2 Interactions of particles with matter	13
1.3 Collider experiments	22
1.4 Measurements at particle accelerators	25
Summary	27
Problems	28
2 Underlying concepts	30
2.1 Units in particle physics	30
2.2 Special relativity	33
2.3 Non-relativistic quantum mechanics	40
Summary	54
Problems	55
3 Decay rates and cross sections	58
3.1 Fermi's golden rule	58
3.2 Phase space and wavefunction normalisation	59
3.3 Particle decays	66
3.4 Interaction cross sections	69
3.5 Differential cross sections	72
Summary	77
Problems	78
4 The Dirac equation	80
4.1 The Klein–Gordon equation	80
4.2 The Dirac equation	82
4.3 Probability density and probability current	85
4.4 *Spin and the Dirac equation	86
4.5 Covariant form of the Dirac equation	89

4.6	Solutions to the Dirac equation	92
4.7	Antiparticles	96
4.8	Spin and helicity states	104
4.9	Intrinsic parity of Dirac fermions	108
	Summary	111
	Problems	112
5	Interaction by particle exchange	114
5.1	First- and second-order perturbation theory	114
5.2	Feynman diagrams and virtual particles	118
5.3	Introduction to QED	121
5.4	Feynman rules for QED	124
	Summary	127
	Problems	127
6	Electron–positron annihilation	128
6.1	Calculations in perturbation theory	128
6.2	Electron–positron annihilation	130
6.3	Spin in electron–positron annihilation	139
6.4	Chirality	140
6.5	*Trace techniques	144
	Summary	157
	Problems	158
7	Electron–proton elastic scattering	160
7.1	Probing the structure of the proton	160
7.2	Rutherford and Mott scattering	161
7.3	Form factors	166
7.4	Relativistic electron–proton elastic scattering	168
7.5	The Rosenbluth formula	171
	Summary	176
	Problems	176
8	Deep inelastic scattering	178
8.1	Electron–proton inelastic scattering	178
8.2	Deep inelastic scattering	183
8.3	Electron–quark scattering	186
8.4	The quark–parton model	189
8.5	Electron–proton scattering at the HERA collider	199
8.6	Parton distribution function measurements	202
	Summary	203
	Problems	204

9	Symmetries and the quark model	207
9.1	Symmetries in quantum mechanics	207
9.2	Flavour symmetry	211
9.3	Combining quarks into baryons	215
9.4	Ground state baryon wavefunctions	219
9.5	Isospin representation of antiquarks	221
9.6	SU(3) flavour symmetry	223
	Summary	238
9.7	*Addendum: Flavour symmetry revisited	239
	Problems	240
10	Quantum Chromodynamics (QCD)	242
10.1	The local gauge principle	242
10.2	Colour and QCD	245
10.3	Gluons	247
10.4	Colour confinement	248
10.5	Running of α_S and asymptotic freedom	253
10.6	QCD in electron–positron annihilation	259
10.7	Colour factors	264
10.8	Heavy mesons and the QCD colour potential	271
10.9	Hadron–hadron collisions	274
	Summary	282
	Problems	283
11	The weak interaction	285
11.1	The weak charged-current interaction	285
11.2	Parity	285
11.3	$V - A$ structure of the weak interaction	290
11.4	Chiral structure of the weak interaction	293
11.5	The W-boson propagator	295
11.6	Helicity in pion decay	298
11.7	Experimental evidence for $V - A$	303
	Summary	304
	Problems	304
12	The weak interactions of leptons	307
12.1	Lepton universality	307
12.2	Neutrino scattering	309
12.3	Neutrino scattering experiments	319
12.4	Structure functions in neutrino interactions	322
12.5	Charged-current electron–proton scattering	324

Summary	327
Problems	327
13 Neutrinos and neutrino oscillations	329
13.1 Neutrino flavours	329
13.2 Solar neutrinos	330
13.3 Mass and weak eigenstates	336
13.4 Neutrino oscillations of two flavours	338
13.5 Neutrino oscillations of three flavours	342
13.6 Neutrino oscillation experiments	351
13.7 Reactor experiments	353
13.8 Long-baseline neutrino experiments	357
13.9 The global picture	360
Summary	361
Problems	362
14 CP violation and weak hadronic interactions	364
14.1 CP violation in the early Universe	364
14.2 The weak interactions of quarks	365
14.3 The CKM matrix	368
14.4 The neutral kaon system	371
14.5 Strangeness oscillations	384
14.6 B-meson physics	394
14.7 CP violation in the Standard Model	402
Summary	405
Problems	405
15 Electroweak unification	408
15.1 Properties of the W bosons	408
15.2 The weak interaction gauge group	415
15.3 Electroweak unification	418
15.4 Decays of the Z	424
Summary	426
Problems	426
16 Tests of the Standard Model	428
16.1 The Z resonance	428
16.2 The Large Electron–Positron collider	434
16.3 Properties of the W boson	442
16.4 Quantum loop corrections	448
16.5 The top quark	450

Summary	456
Problems	457
17 The Higgs boson	460
17.1 The need for the Higgs boson	460
17.2 Lagrangians in Quantum Field Theory	461
17.3 Local gauge invariance	467
17.4 Particle masses	469
17.5 The Higgs mechanism	470
17.6 Properties of the Higgs boson	487
17.7 The discovery of the Higgs boson	490
Summary	493
17.8 *Addendum: Neutrino masses	494
Problems	497
18 The Standard Model and beyond	499
18.1 The Standard Model	499
18.2 Open questions in particle physics	501
18.3 Closing words	510
Appendix A The Dirac delta-function	512
A.1 Definition of the Dirac delta-function	512
A.2 Fourier transform of a delta-function	513
A.3 Delta-function of a function	513
Appendix B Dirac equation	515
B.1 Magnetic moment of a Dirac fermion	515
B.2 Covariance of the Dirac equation	517
B.3 Four-vector current	520
Problems	521
Appendix C The low-mass hadrons	523
Appendix D Gauge boson polarisation states	525
D.1 Classical electromagnetism	525
D.2 Photon polarisation states	527
D.3 Polarisation states of massive spin-1 particles	528
D.4 Polarisation sums	530
Appendix E Noether's theorem	535
Problem	536

Appendix F	Non-Abelian gauge theories	537
<i>References</i>		543
<i>Further reading</i>		545
<i>Index</i>		546