Contents

I	Pr	eliminaries and Tools	1
1	Intr	oduction	3
2	Symmetries of Space-Time		
	2.1	Relativistic particle kinematics	10
	2.2	Natural units	12
	2.3	A little theory of discrete groups	14
	2.4	A little theory of continuous groups	18
	2.5	Discrete space-time symmetries	22
	Exer	rcises	23
3	Rela	ativistic Wave Equations	25
	3.1	The Klein-Gordon equation	25
	3.2	Fields and particles	28
	3.3	Maxwell's equations	29
	3.4	The Dirac equation	32
	3.5	Relativistic normalization of states	37
	3.6	Spin and statistics	39
	Exer	rcises	40
4	The	Hydrogen Atom and Positronium	43
	4.1	The ideal hydrogen atom	43
	4.2	Fine structure and hyperfine structure	44
	4.3	Positronium	48
	Exer	rcises	51
5	The	Quark Model	55
	5.1		55
	5.2	Charmonium	58
	5.3	The light mesons	65
	5.4	The heavy mesons	68
	5.5	The baryons	69
	Exer	cises	74
6	Detectors of Elementary Particles 7		
	6.1	Energy loss by ionization	78
	6.2	Electromagnetic showers	81
	6.3	Further effects of nuclear scattering	85
	6.4	Energy loss through macroscopic properties of the medium	87

	6.5 Detector systems for collider physics Exercises	87 93
7	Tools for Calculation	95
	7.1 Observables in particle experiments	95
	7.2 Master formulae for partial width and cross sections	97
	7.3 Phase space	99
	7.4 Example: $\pi^+\pi^-$ scattering at the ρ resonance	101
	Exercises	106
II	The Strong Interaction	111
8	Electron-Positron Annihilation	113
	8.1 The reaction $e^+e^- \rightarrow \mu^+\mu^-$	113
	8.2 Properties of massless spin- $\frac{1}{2}$ fermions	115
	8.3 Evaluation of the matrix elements for $e^+e^- \rightarrow \mu^+\mu^-$	118
	8.4 Evaluation of the cross section for $e^+e^- \to \mu^+\mu^-$	121
	8.5 e^+e^- annihilation to hadrons	122
	Exercises	127
9	Deep Inelastic Electron Scattering	129
	9.1 The SLAC-MIT experiment	129
	9.2 The parton model	133
	9.3 Crossing symmetry	134
	9.4 Cross section for electron-quark scattering	139
	9.5 The cross section for deep inelastic scattering	141
	9.6 Bjorken scaling	144
	Exercises	146
10	The Gluon	149
	10.1 Measurement of parton distribution functions	149
	10.2 Photon emission in $e^+e^- \to q\overline{q}$	155
	10.3 Three-jet events in e^+e^- annihilation	160
	10.4 Effects of gluon emission on pdfs	165
	Exercises	168
11	Quantum Chromodynamics	169
	11.1 Lagrangian dynamics and gauge invariance	169
	11.2 More about Lie groups	171
	11.3 Non-Abelian gauge symmetry	173
	11.4 Formulation of QCD	176
	11.5 Gluon emission in QCD	176
	11.6 Vacuum polarization	177 179
	11.7 Asymptotic freedom Evercises	184
	Exercises	
12	Partons and Jets	187
	12.1 Altarelli-Parisi evolution of parton distribution functions	187

	12.2 The structure of jets	191
	Exercises	197
12	QCD at Hadron Colliders	199
19	13.1 Hadron scattering at low momentum transfer	199
	13.2 Hadron scattering at large momentum transfer	204
	13.3 Jet structure observables for hadron collisions	208
	13.4 The width of a jet in hadron-hadron collisions	209
	13.5 Production of the top quark	213
	Exercises	215
14	Chiral Symmetry	217
	14.1 Symmetries of QCD with zero quark masses	217
	14.2 Spontaneous symmetry breaking	219
	14.3 Goldstone bosons	223
	14.4 Properties of π mesons as Goldstone bosons	224
	Exercises	228
TT	I The Weak Interaction	231
II	I The Weak Interaction	201
15	The Current-Current Model of the Weak Interaction	233
	15.1 Development of the V-A theory of the weak interaction	234
	15.2 Predictions of the V-A theory for leptons	235
	15.3 Predictions of the V-A theory for pion decay	243
	15.4 Predictions of the V-A theory for neutrino scattering	245
	Exercises	249
16	Gauge Theories with Spontaneous Symmetry Breaking	251
	16.1 Field equations for a massive photon	251
	16.2 Model field equations with a non-Abelian gauge symmetry	253
	16.3 The Glashow-Salam-Weinberg electroweak model	255
	16.4 The neutral current weak interaction	260
	Exercises	263
17	The W and Z Bosons	265
	17.1 Properties of the W boson	265
	17.2 W production in pp collisions	269
	17.3 Properties of the Z boson	270
	17.4 Precision tests of the electroweak model	271
	Exercises	280
18	Quark Mixing Angles and Weak Decays	283
	18.1 The Cabibbo mixing angle	283
	18.2 Quark and lepton mass terms in the Standard Model	285
	18.3 Discrete space-time symmetries and the Standard Model	287
	18.4 The Standard Model of particle physics	289
	18.5 Quark mixing including heavy quarks	291
	Exercises	293

19	CP Violation	295
	19.1 <i>CP</i> violation in the $K^0-\overline{K}^0$ system	295
	19.2 Electric dipole moments	302
	19.3 CP violation in the $B^0-\overline{B}^0$ system	303
	Exercises	310
00		
20	Neutrino Masses and Mixings	313
	20.1 Neutrino mass and β decay	313
	20.2 Adding neutrino mass to the Standard Model	315
	20.3 Measurements of neutrino flavor mixing	319
	Exercises	324
21	The Higgs Boson	327
	21.1 Constraints on the Higgs field from the weak interaction	327
	21.2 Expected properties of the Higgs boson	329
	21.3 Measurements of Higgs boson properties at the LHC	332
	Exercises	340
	LACICISCS	940
IV	Epilogue	343
22	Epilogue	345
A	Notation	355
В	Conversion factors and physical constants	359
C	Formulae for the creation and destruction of elementar	·v
	particles	361
	ange Theories with Spontaneous Eganostay Eighhang	
D	Master formulae for the computation of cross section	
	and partial widths	363
E	QCD formulae for hadron collisions	365
Wa		367
Re	eferences	301
	dev	377