

Contents

List of Figures	xi
Preface	xiii
The Authors	xv
CHAPTER 1 ■ INTRODUCTION	1
1.1 QUANTUM ELECTRODYNAMICS	1
1.2 UNITS AND OTHER CONVENTIONS.	3
CHAPTER 2 ■ THE FEYNMAN PATH INTEGRAL	5
2.1 CALCULATION OF THE TRANSITION AMPLITUDE	5
2.2 THE LATTICE APPROXIMATION	8
2.3 THE CLASSICAL LIMIT	9
2.4 TIME AS A COMPLEX VARIABLE	9
2.5 STATISTICAL MECHANICS	11
2.6 GREEN'S FUNCTIONS	12
CHAPTER 3 ■ TOWARDS A FIELD THEORY	17
3.1 THE GENERATING FUNCTIONAL	20
3.2 THE HARMONIC OSCILLATOR	23
3.3 FREE SCALAR FIELDS: PROPAGATOR AND GENERATING FUNCTIONAL	28
3.4 FREE SCALAR FIELD: ONE-PARTICLE STATES	31
3.5 CREATION AND DESTRUCTION OPERATORS	33
CHAPTER 4 ■ EQUATIONS OF MOTION, SYMMETRIES AND WARD'S IDENTITY	37
4.1 SUM OVER PATHS AND OPERATORS	38
4.1.1 Derivatives	39

4.2	THE FUNDAMENTAL IDENTITY	39
4.3	QUANTUM MECHANICS	41
4.3.1	Equations of motion and commutation rules	41
4.3.2	Symmetries	43
4.3.3	The Hamiltonian function	45
4.4	FIELD THEORY	46
4.4.1	Symmetries in field theory	47
4.4.2	Ward's identity	49
4.5	THE SYMMETRIES OF THE VACUUM	52
CHAPTER	5 ■ THE ELECTROMAGNETIC FIELD	55
5.1	THE CHOICE OF GAUGE	56
5.2	GENERATING FUNCTIONAL AND PROPAGATOR	58
5.3	SINGLE PHOTON STATES	59
5.4	VIRTUAL PHOTONS	62
CHAPTER	6 ■ FERMION FIELDS	67
6.1	HARMONIC AND FERMI OSCILLATORS	67
6.1.1	Anticommuting variables	69
6.1.2	Sum over paths for the two oscillators	70
6.1.3	Gaussian integrals for commuting and anticommuting variables	74
6.2	QUANTISATION OF THE DIRAC FIELD	76
6.2.1	Fermion propagator	79
6.2.2	The spin-statistics theorem	79
6.2.3	One-particle states of the Dirac field	81
CHAPTER	7 ■ SCATTERING PROCESSES AND THE S-MATRIX	85
7.1	"IN" STATES AND "OUT" STATES	86
7.2	SCATTERING AMPLITUDES AND THE S -MATRIX	89
7.3	CONSERVED QUANTITIES	90
7.4	THE LSZ REDUCTION FORMULAE	91
CHAPTER	8 ■ PERTURBATIVE GREEN'S FUNCTIONS IN $\lambda\phi^4$	99
8.1	THE PERTURBATIVE GENERATING FUNCTIONAL	100
8.2	FEYNMAN RULES FOR GREEN'S FUNCTIONS	104

8.3	CONNECTED PARTS AND VACUUM DIAGRAMS	110
8.4	PERTURBATIVE TWO-POINT GREEN'S FUNCTION	112
CHAPTER 9	S-MATRIX FEYNMAN DIAGRAMS IN $\lambda\phi^4$	117
9.1	ONE-PARTICLE IRREDUCIBLE DIAGRAMS	117
9.2	FEYNMAN RULES FOR THE S -MATRIX ELEMENTS	120
CHAPTER 10	QUANTUM ELECTRODYNAMICS	123
10.1	FEYNMAN DIAGRAMS FOR THE GENERATING FUNCTIONAL	125
10.2	TWO-POINT FUNCTIONS	128
10.3	REDUCTION FORMULAE	130
10.4	FEYNMAN DIAGRAMS FOR THE S -MATRIX	132
10.5	COMBINATORIALS	136
CHAPTER 11	RENORMALISATION OF QED	139
11.1	THE PHOTON PROPAGATOR	142
11.2	RENORMALISATION OF THE CHARGE	145
11.3	THE ELECTRON PROPAGATOR	146
11.3.1	The propagator to all orders	149
11.4	THE VERTEX	151
11.5	WARD'S IDENTITY	153
CHAPTER 12	APPLICATIONS OF QED	155
12.1	SCATTERING IN AN EXTERNAL FIELD	155
12.2	BREMSSTRAHLUNG AND INFRARED DIVERGENCE	158
12.3	THE LAMB SHIFT	162
12.4	VACUUM POLARISATION	166
12.4.1	Calculation of the tensor $\Pi^{\mu\nu}(k)$ to one loop	166
12.5	THE ANOMALOUS MAGNETIC MOMENT	169
12.5.1	Preliminaries	169
12.5.2	The calculation	171
CHAPTER 13	RENORMALISATION GROUP OF QED	175
13.1	EFFECTIVE ELECTRIC CHARGE	176
13.2	THE GELL-MANN AND LOW EQUATION	179

13.3	THE QED β FUNCTION	180
13.4	ASYMPTOTIC VARIATION OF THE EFFECTIVE CHARGE	181
CHAPTER 14 ■ QUANTISING A NON-ABELIAN THEORY		183
14.1	FUNDAMENTALS	183
14.2	QUARKS IN QUANTUM CHROMODYNAMICS	186
14.3	THE FADDEEV-POPOV DETERMINANT	188
14.4	FEYNMAN RULES	192
CHAPTER 15 ■ THE β FUNCTION IN QCD		195
15.1	VACUUM POLARISATION	195
15.2	CORRECTIONS TO QUARK PROPAGATOR AND VERTEX	200
15.3	ASYMPTOTIC FREEDOM	202
CHAPTER 16 ■ UNITARITY AND GHOSTS		205
16.1	THE CUTKOSKY RULE	206
16.2	THE INELASTIC REACTION $u + \bar{u} \rightarrow d + \bar{d}$	207
16.3	THE CASE OF QED	210
16.4	NON-ABELIAN GAUGE THEORIES	212
CHAPTER 17 ■ EFFECTIVE CONSTANTS AT HIGH ENERGY AND GRAND UNIFICATION		217
17.1	THE DETERMINATION OF α_s	217
17.2	THE LANDAU POLE AND THE CONTINUUM LIMIT	218
17.3	EFFECTIVE CONSTANTS OF THE STANDARD THEORY	220
17.4	GRAND UNIFICATION AND OTHER HYPOTHESES	224
CHAPTER 18 ■ LIMITS ON THE MASS OF THE HIGGS BOSON		229
18.1	SCALAR FIELDS IN THE STANDARD THEORY	229
18.2	LIMITS ON THE MASS OF THE HIGGS BOSON	234
CHAPTER 19 ■ THE WEAK MUON ANOMALY		239
19.1	THE R_ξ GAUGE	240
19.2	MUON ANOMALY: W EXCHANGE	244
19.3	Z AND HIGGS BOSON EXCHANGE	247
19.4	COMPARISON WITH DATA	248

CHAPTER 20 ■ EFFECTIVE POTENTIAL AND NATURALNESS	251
20.1 EFFECTIVE POTENTIAL	251
20.2 EXPANSION AROUND THE CLASSICAL LIMIT	253
20.3 LOOP EXPANSION OF THE POTENTIAL	257
20.4 ONE LOOP POTENTIAL IN THE STANDARD THEORY	258
20.5 NON-NATURALNESS OF THE STANDARD THEORY	264
APPENDIX A ■ Transition Amplitude Calculation	269
A.1 TRANSITION AMPLITUDE FOR ZERO POTENTIAL	269
APPENDIX B ■ Connected Diagrams	271
B.1 GENERATING FUNCTIONAL OF CONNECTED DIAGRAMMS	271
APPENDIX C ■ Lorentz invariance and one-particle states	275
C.1 RENORMALISATION CONSTANTS	275
APPENDIX D ■ Reduction formulae	279
D.1 REDUCTION FORMULAE FOR THE COMPTON SCATTERING AMPLITUDE	279
APPENDIX E ■ Integrals	283
E.1 INTEGRATION IN D DIMENSIONS	283
E.2 FEYNMAN PARAMETERS	285
APPENDIX F ■ $\beta(\lambda)$ and $\beta(g_t)$ functions	287
F.1 CALCULATION OF THE $\beta(\lambda)$ AND $\beta(g_t)$ FUNCTIONS	287
F.2 $\beta(\lambda)$	287
F.3 $\beta(g_t)$	293
Bibliography	295
Index	299