
Contents

<i>List of Figures and Tables</i>	<i>page</i> xii
<i>Preface</i>	xv
<i>Acknowledgments</i>	xvii
1 Basics of Quantum Field Theory	1
1.1 Why Quantum Field Theory?	1
1.2 Special Relativity	3
1.3 Free Scalar Fields, Mode Decomposition	7
1.4 Interacting Scalar Particles	14
1.5 From Field Correlations to Reaction Rates	17
1.6 Källén–Lehmann Spectral Representation	24
1.7 Generating Functional	27
Exercises	32
2 Perturbation Theory	35
2.1 Perturbative Expansion and Feynman Rules	35
2.2 Calculation of Loop Integrals	41
2.3 Ultraviolet Divergences and Renormalization	44
2.4 Perturbative Unitarity	53
Exercises	61
3 Quantum Electrodynamics	63
3.1 Spin-1/2 Fields	63
3.2 Spin-1 Fields	70
3.3 Quantum Electrodynamics	74
3.4 Charge Conservation, Ward–Takahashi Identities	80
3.5 Ultraviolet Renormalization	82
3.6 Cutting Rules in QED and Unitarity	86

3.7	Infrared Divergences	88
	Exercises	93
4	Spontaneous Symmetry Breaking	95
4.1	Potential Energy Landscape	95
4.2	Conserved Currents and Charges	101
4.3	Spectral Properties	103
4.4	Coleman's Theorem	105
4.5	Linear Sigma Model	107
4.6	Heisenberg Model of Ferromagnetism	111
	Exercises	114
5	Functional Quantization	116
5.1	Path Integral in Quantum Mechanics	116
5.2	Functional Manipulations	120
5.3	Path Integral in Scalar Field Theory	125
5.4	Functional Determinants	127
5.5	Quantum Effective Action	129
5.6	Two-Particle Irreducible Effective Action	138
5.7	Euclidean Path Integral and Statistical Mechanics	144
	Exercises	147
6	Path Integrals for Fermions and Photons	150
6.1	Grassmann Variables	150
6.2	Path Integral for Fermions	156
6.3	Path Integral for Photons	157
6.4	Schwinger–Dyson Equations	160
6.5	Quantum Anomalies	162
	Exercises	170
7	Non-Abelian Gauge Symmetry	173
7.1	Non-Abelian Lie Groups and Algebras	173
7.2	Yang–Mills Lagrangian	181
7.3	Non-Abelian Gauge Theories	185
7.4	Spontaneous Gauge Symmetry Breaking	190
7.5	θ -term and Strong-CP Problem	194
7.6	Non-Local Gauge Invariant Operators	201
	Exercises	209

8	Quantization of Yang–Mills Theory	212
8.1	Naive Quantization of the Gauge Bosons	212
8.2	Gauge Fixing	214
8.3	Faddeev–Popov Quantization and Ghost Fields	215
8.4	Feynman Rules for Non-Abelian Gauge Theories	217
8.5	On-Shell Non-Abelian Ward–Takahashi Identities	221
8.6	Ghosts and Unitarity	223
	Exercises	232
9	Renormalization of Gauge Theories	234
9.1	Ultraviolet Power Counting	234
9.2	Symmetries of the Quantum Effective Action	236
9.3	Renormalizability	241
9.4	Background Field Method	245
	Exercises	251
10	Renormalization Group	252
10.1	Scale Dependence of Correlation Functions	252
10.2	Correlators Containing Composite Operators	256
10.3	Operator Product Expansion	258
10.4	Example: QCD Corrections to Weak Decays	261
10.5	Non-Perturbative Renormalization Group	267
	Exercises	276
11	Effective Field Theories	278
11.1	General Principles of Effective Theories	279
11.2	Example: Fermi Theory of Weak Decays	282
11.3	The Standard Model as an Effective Field Theory	285
11.4	Effective Theories in QCD	291
11.5	EFT of Spontaneous Symmetry-Breaking	300
	Exercises	309
12	Quantum Anomalies	312
12.1	Axial Anomalies in a Gauge Background	312
12.2	Generalizations	323
12.3	Wess–Zumino Consistency Conditions	329
12.4	't Hooft Anomaly Matching	333

12.5 Scale Anomalies	334
Exercises	341
13 Localized Field Configurations	342
13.1 Domain Walls	343
13.2 Monopoles	346
13.3 Instantons	355
13.4 Skyrmions	366
Exercises	370
14 Modern Tools for Tree Amplitudes	372
14.1 Color Decomposition of Gluon Amplitudes	373
14.2 Spinor-Helicity Formalism	379
14.3 Britto–Cachazo–Feng–Witten On-Shell Recursion	388
14.4 Tree-Level Gravitational Amplitudes	398
14.5 Cachazo–Svrcek–Witten Rules	406
Exercises	415
15 Worldline Formalism	418
15.1 Worldline Representation	418
15.2 Quantum Electrodynamics	423
15.3 Schwinger Mechanism	427
15.4 Calculation of One-Loop Amplitudes	430
Exercises	438
16 Lattice Field Theory	440
16.1 Discretization of Bosonic Actions	441
16.2 Lattice Fermions	445
16.3 Hadron Mass Determination on the Lattice	449
16.4 Wilson Loops and Color Confinement	451
16.5 Gauge Fixing on the Lattice	454
16.6 Lattice Hamiltonian	457
16.7 Lattice Worldline Formalism	458
Exercises	462
17 Quantum Field Theory at Finite Temperature	465
17.1 Canonical Thermal Ensemble	465
17.2 Finite-T Perturbation Theory	466

CONTENTS	xi
17.3 Large-Distance Effective Theories	482
17.4 Out-of-Equilibrium Systems	495
Exercises	501
18 Strong Fields and Semi-Classical Methods	504
18.1 Situations Involving Strong Fields	505
18.2 Observables at Leading and Next-to-Leading Orders	512
18.3 Green's Formulas	517
18.4 Mode Functions	526
18.5 Multi-Point Correlation Functions at Tree Level	530
Exercises	543
19 From Trees to Loops	546
19.1 Dualities Between Loops and Trees	546
19.2 Reduction of One-Loop Amplitudes	553
19.3 One-Loop Amplitudes from Unitarity Cuts	564
19.4 The Frontier: Multi-Loop Amplitudes	573
Exercises	581
<i>Further Reading</i>	584
<i>Index</i>	586