

QUANTUM FIELD THEORY IN A NUTSHELL

A. ZEE

Kavli Institute for Theoretical Physics
University of California at Santa Barbara

PRINCETON UNIVERSITY PRESS
PRINCETON AND OXFORD

Contents

Preface	xi
Convention, Notation, and Units	xv

PART I MOTIVATION AND FOUNDATION

I.1	Who Needs It?	3
I.2	Path Integral Formulation of Quantum Physics	7
I.3	From Mattress to Field	16
I.4	From Field to Particle to Force	24
I.5	Coulomb and Newton: Repulsion and Attraction	30
I.6	Inverse Square Law and the Floating 3-Brane	38
I.7	Feynman Diagrams	41
I.8	Quantizing Canonically and Disturbing the Vacuum	61
I.9	Symmetry	70
I.10	Field Theory in Curved Spacetime	76
I.11	Field Theory Redux	84

PART II DIRAC AND THE SPINOR

II.1	The Dirac Equation	89
II.2	Quantizing the Dirac Field	103
II.3	Lorentz Group and Weyl Spinors	111
II.4	Spin-Statistics Connection	117
II.5	Vacuum Energy, Grassmann Integrals, and Feynman Diagrams for Fermions	121
II.6	Electron Scattering and Gauge Invariance	130
II.7	Diagrammatic Proof of Gauge Invariance	135

PART III
RENORMALIZATION AND GAUGE INVARIANCE

III.1	Cutting Off Our Ignorance	145
III.2	Renormalizable versus Nonrenormalizable	154
III.3	Counterterms and Physical Perturbation Theory	158
III.4	Gauge Invariance: A Photon Can Find No Rest	167
III.5	Field Theory without Relativity	172
III.6	The Magnetic Moment of the Electron	177
III.7	Polarizing the Vacuum and Renormalizing the Charge	183

PART IV
SYMMETRY AND SYMMETRY BREAKING

IV.1	Symmetry Breaking	193
IV.2	The Pion as a Nambu-Goldstone Boson	202
IV.3	Effective Potential	208
IV.4	Magnetic Monopole	217
IV.5	Nonabelian Gauge Theory	226
IV.6	The Anderson-Higgs Mechanism	236
IV.7	Chiral Anomaly	243

PART V
FIELD THEORY AND COLLECTIVE PHENOMENA

V.1	Superfluids	257
V.2	Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature	261
V.3	Landau-Ginzburg Theory of Critical Phenomena	267
V.4	Superconductivity	270
V.5	Peierls Instability	273
V.6	Solitons	277
V.7	Vortices, Monopoles, and Instantons	282

PART VI
FIELD THEORY AND CONDENSED MATTER

VI.1	Fractional Statistics, Chern-Simons Term, and Topological Field Theory	293
VI.2	Quantum Hall Fluids	300
VI.3	Duality	309
VI.4	The σ Models as Effective Field Theories	318
VI.5	Ferromagnets and Antiferromagnets	322
VI.6	Surface Growth and Field Theory	326
VI.7	Disorder: Replicas and Grassmannian Symmetry	330
VI.8	Renormalization Group Flow as a Natural Concept in High Energy and Condensed Matter Physics	337

PART VII
GRAND UNIFICATION

VII.1	Quantizing Yang-Mills Theory and Lattice Gauge Theory . . .	353
VII.2	Electroweak Unification	361
VII.3	Quantum Chromodynamics	368
VII.4	Large N Expansion	377
VII.5	Grand Unification	391
VII.6	Protons Are Not Forever	397
VII.7	SO(10) Unification	405

PART VIII
GRAVITY AND BEYOND

VIII.1	Gravity as a Field Theory and the Kaluza-Klein Picture	419
VIII.2	The Cosmological Constant Problem and the Cosmic Coincidence Problem	434
VIII.3	Effective Field Theory Approach to Understanding Nature . . .	437
VIII.4	Supersymmetry: A Very Brief Introduction	443
VIII.5	A Glimpse of String Theory as a 2-Dimensional Field Theory	452

Closing Words	455
-------------------------	-----

APPENDIXES

A	Gaussian Integration and the Central Identity of Quantum Field Theory	459
B	A Brief Review of Group Theory	461
C	Feynman Rules	471
D	Various Identities and Feynman Integrals	475
E	Dotted and Undotted Indices and the Majorana Spinor	479
	Solutions to Selected Exercises	483
	Further Reading	501
	Index	505