Contents

	xi
ntion, Notation, and Units	xv
PART I	
MOTIVATION AND FOUNDATION	
Who Needs It?	3
Path Integral Formulation of Quantum Physics	7
From Mattress to Field	16
From Field to Particle to Force.	24
Coulomb and Newton: Repulsion and Attraction	30
Inverse Square Law and the Floating 3-Brane	38
Feynman Diagrams	41
Quantizing Canonically and Disturbing the Vacuum	61
Symmetry	70
Field Theory in Curved Spacetime	76
Field Theory Redux	84
PART II	
DIRAC AND THE SPINOR	
The Dirac Equation	89
Quantizing the Dirac Field	103
	111
	117
Vacuum Energy, Grassmann Integrals, and Feynman	
Diagrams for Fermions	121
Electron Scattering and Gauge Invariance	130
Diagrammatic Proof of Gauge Invariance	135
	PART I MOTIVATION AND FOUNDATION Who Needs It? Path Integral Formulation of Quantum Physics From Mattress to Field From Field to Particle to Force. Coulomb and Newton: Repulsion and Attraction Inverse Square Law and the Floating 3-Brane Feynman Diagrams Quantizing Canonically and Disturbing the Vacuum Symmetry Field Theory in Curved Spacetime Field Theory Redux PART II DIRAC AND THE SPINOR The Dirac Equation Quantizing the Dirac Field Lorentz Group and Weyl Spinors Spin-Statistics Connection Vacuum Energy, Grassmann Integrals, and Feynman Diagrams for Fermions Electron Scattering and Gauge Invariance

viii Contents

TIL1 Cutting Off Our Ignorance 145 ill.2 Renormalizable versus Nonrenormalizable 154 ill.3 Counterterms and Physical Perturbation Theory 158 TIL4 Gauge Invariance: A Photon Can Find No Rest 167 ill.5 Field Theory without Relativity 172 ill.6 The Magnetic Moment of the Electron 177 TIL7 Polarizing the Vacuum and Renormalizing the Charge 183 PART IV SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking 193 IV.2 The Pion as a Nambu-Goldstone Boson 202 IV.3 Effective Potential 208 IVA 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 VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261		RENORMALIZATION AND GAUGE INVARIANCE	
ill.2 Renormalizable versus Nonrenormalizable 154 ill.3 Counterterms and Physical Perturbation Theory 158 TIL4 Gauge Invariance: A Photon Can Find No Rest 167 ill.5 Field Theory without Relativity 172 ill.6 The Magnetic Moment of the Electron 177 TIL7 Polarizing the Vacuum and Renormalizing the Charge 183 PART IV SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking 193 IV.2 The Pion as a Nambu-Goldstone Boson 202 IV.3 Effective Potential 208 IVA 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 VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267<	TILl	Cutting Off Our Ignorance	1/15
ill.3 Counterterms and Physical Perturbation Theory 158 TIL4 Gauge Invariance: A Photon Can Find No Rest 167 ill.5 Field Theory without Relativity 172 ill6 The Magnetic Moment of the Electron 177 TIL7 Polarizing the Vacuum and Renormalizing the Charge 183 PART IV SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking 193 IV.2 The Pion as a Nambu-Goldstone Boson 202 IV.3 Effective Potential 208 IVA 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 VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270	ill.2		
TIL4 Gauge Invariance: A Photon Can Find No Rest 167 111.5 Field Theory without Relativity 172 1116 The Magnetic Moment of the Electron 177 TIL7 Polarizing the Vacuum and Renormalizing the Charge 183 PART IV SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking 193 IV.2 The Pion as a Nambu-Goldstone Boson 202 IV.3 Effective Potential 208 IVA 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 VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 <td>ill.3</td> <td></td> <td></td>	ill.3		
ill.5 Field Theory without Relativity 172 ill6 The Magnetic Moment of the Electron 177 TIL7 Polarizing the Vacuum and Renormalizing the Charge 183 PART IV SYMMETRY BREAKING IV1 Symmetry Breaking 193 IV.2 The Pion as a Nambu-Goldstone Boson 202 IV.3 Effective Potential 208 IVA 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 VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277	TIL4		
The Magnetic Moment of the Electron	ill.5		
PART IV Symmetry Breaking 193	il16		
PART IV SYMMETRY AND SYMMETRY BREAKING	TIL7		
SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking			200
SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking			
SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking			
SYMMETRY AND SYMMETRY BREAKING IV1 Symmetry Breaking		PART IV	
IV.2 The Pion as a Nambu-Goldstone Boson 202 IV.3 Effective Potential 208 IVA 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 VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277			
IV.3 Effective Potential	IV1	Symmetry Breaking	193
IVA Magnetic Monopole	IV.2	The Pion as a Nambu-Goldstone Boson	202
IVA Magnetic Monopole	IV.3		208
IV.6 The Anderson-Higgs Mechanism. 236 IV.7 Chiral Anomaly	IVA		217
IV.6 The Anderson-Higgs Mechanism. 236 IV.7 Chiral Anomaly	IV.5	Nonabelian Gauge Theory	226
PART V FIELD THEORY AND COLLECTIVE PHENOMENA VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277	IV.6		236
FIELD THEORY AND COLLECTIVE PHENOMENA VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277	IV.7	Chiral Anomaly	243
FIELD THEORY AND COLLECTIVE PHENOMENA VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277			
FIELD THEORY AND COLLECTIVE PHENOMENA VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277			
FIELD THEORY AND COLLECTIVE PHENOMENA VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature 261 V.3 Landau-Ginzburg Theory of Critical Phenomena 267 VA Superconductivity 270 V.5 Peierls Instability 273 V6 Solitons. 277			
VI Superfluids 257 V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature			
V2 Euclid, Boltzmann, Hawking, and Field Theory at Finite Temperature	***		
Finite Temperature			257
V.3Landau-GinzburgTheory of Critical Phenomena267VASuperconductivity270V.5Peierls Instability273V6Solitons.277	V2	•	261
VA Superconductivity	V.3		
V.5 Peierls Instability	VA		
V6 Solitons	V.5		
V7	V6		
	V7		282

PART III

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
VIA	The a 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	
VIT.l	Quantizing Yang-Mills Theory and Lattice Gauge Theory	353
VIT.2	Electroweak Unification	361
VII.2	Quantum Chromodynamics	368
VITA	Large N Expansion	377
VII.5	Grand Unification	391
VII.6	Protons Are Not Forever	397
VII.0	SO(IO) Unification	405
V11./	50(10) Chinication	
	PART VIII	
	GRAVITY AND BEYOND	
	GRAVIII AND DETOND	
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
VID.3		437
VIII.4	Supersymmetry: A Very Brief Introduction	443
VIII.5	A Glimpse of String Theory as a 2-Dimensional	
	Field Theory	452

X	Contents
X	Contents

	APPENDIXES	
Α	Gaussian Integration and the Central Identity of	
	Quantum Field Theory	459
В	A Brief Review of Group Theory.	46
С	Feynman Rules	47
D	Various Identities and Feynman Integrals	475
E	Dotted and Undotted Indices and the Majorana Spinor	479
Soluti	ions to Selected Exercises	483
Furthe	er Reading	50
Index		50: