

Contents

Preface	vii
Acknowledgments	xi

Part I. First Quantization and Path Integrals

CHAPTER 1

Path Integrals and Point Particles	3
1.1. Why Strings?	3
1.2. Historical Review of Gauge Theory	7
1.3. Path Integrals and Point Particles	18
1.4. Relativistic Point Particles	25
1.5. First and Second Quantization	28
1.6. Faddeev–Popov Quantization	30
1.7. Second Quantization	34
1.8. Harmonic Oscillators	37
1.9. Currents and Second Quantization	40
1.10. Summary	44
References	47

CHAPTER 2

Nambu–Goto Strings	49
2.1. Bosonic Strings	49
2.2. Gupta–Bleuler Quantization	59
2.3. Light Cone Quantization	66
2.4. BRST Quantization	69
2.5. Trees	71
2.6. From Path Integrals to Operators	77
2.7. Projective Invariance and Twists	83

2.8. Closed Strings	86
2.9. Ghost Elimination	89
2.10. Summary	94
References	98

CHAPTER 3

Superstrings	99
3.1. Supersymmetric Point Particles	99
3.2. Two-Dimensional Supersymmetry	102
3.3. Trees	109
3.4. Local 2D Supersymmetry	115
3.5. Quantization	117
3.6. GSO Projection	121
3.7. Superstrings	124
3.8. Light Cone Quantization of the GS Action	126
3.9. Vertices and Trees	132
3.10. Summary	134
References	137

CHAPTER 4

Conformal Field Theory and Kac–Moody Algebras	139
4.1. Conformal Field Theory	139
4.2. Superconformal Field Theory	148
4.3. Spin Fields	153
4.4. Superconformal Ghosts	156
4.5. Fermion Vertex	163
4.6. Spinors and Trees	166
4.7. Kac–Moody Algebras	169
4.8. Supersymmetry	172
4.9. Summary	173
References	175

CHAPTER 5

Multiloops and Teichmüller Spaces	177
5.1. Unitarity	177
5.2. Single-Loop Amplitude	181
5.3. Harmonic Oscillators	184
5.4. Single-Loop Superstring Amplitudes	192
5.5. Closed Loops	194
5.6. Multiloop Amplitudes	199
5.7. Riemann Surfaces and Teichmüller Spaces	209
5.8. Conformal Anomaly	216
5.9. Superstrings	219
5.10. Determinants and Singularities	223
5.11. Moduli Space and Grassmannians	225
5.12. Summary	236
References	240

Part II. Second Quantization and the Search for Geometry

CHAPTER 6

Light Cone Field Theory	245
6.1. Why String Field Theory?	245
6.2. Deriving Point Particle Field Theory	248
6.3. Light Cone Field Theory	252
6.4. Interactions	259
6.5. Neumann Function Method	265
6.6. Equivalence of the Scattering Amplitudes	270
6.7. Four-String Interaction	272
6.8. Superstring Field Theory	277
6.9. Summary	283
References	288

CHAPTER 7

BRST Field Theory	289
7.1. Covariant String Field Theory	289
7.2. BRST Field Theory	295
7.3. Gauge Fixing	298
7.4. Interactions	301
7.5. Axiomatic Formulation	306
7.6. Proof of Equivalence	309
7.7. Closed Strings and Superstrings	315
7.8. Summary	325
References	328

CHAPTER 8

Geometric String Field Theory	331
8.1. Why Geometry?	331
8.2. The String Group	336
8.3. Unified String Group	341
8.4. Representations of the USG	343
8.5. Ghost Sector and the Tangent Space	348
8.6. Connections and Covariant Derivatives	352
8.7. Geometric Derivation of the Action	357
8.8. The Interpolating Gauge	360
8.9. Closed Strings and Superstrings	364
8.10. Summary	368
References	372

Part III. Phenomenology and Model Building

CHAPTER 9

Anomalies and the Atiyah–Singer Theorem	375
9.1. Beyond GUT Phenomenology	375
9.2. Anomalies and Feynman Diagrams	379

9.3. Anomalies in the Functional Formalism	384
9.4. Anomalies and Characteristic Classes	386
9.5. Dirac Index	391
9.6. Gravitational and Gauge Anomalies	394
9.7. Anomaly Cancellation in Strings	404
9.8. A Simple Proof of the Atiyah–Singer Index Theorem	406
9.9. Summary	412
References	416
CHAPTER 10	
Heterotic Strings and Compactification	417
10.1. Compactification	417
10.2. The Heterotic String	422
10.3. Spectrum	427
10.4. Covariant and Fermionic Formulations	430
10.5. Trees	432
10.6. Single-Loop Amplitude	435
10.7. E_8 and Kac–Moody Algebras	439
10.8. 10D Without Supersymmetry	441
10.9. Lorentzian Lattices	446
10.10. Summary	448
References	451
CHAPTER 11	
Calabi–Yau Spaces and Orbifolds	452
11.1. Calabi–Yau Spaces	452
11.2. Review of de Rahm Cohomology	457
11.3. Cohomology and Homology	461
11.4. Kähler Manifolds	467
11.5. Embedding the Spin Connection	474
11.6. Fermion Generations	476
11.7. Wilson Lines	481
11.8. Orbifolds	482
11.9. Four-Dimensional Superstrings	487
11.10. Summary	503
11.11. Conclusion	507
References	509
APPENDIX	
A.1. A Brief Introduction to Group Theory	511
A.2. A Brief Introduction to General Relativity	523
A.3. A Brief Introduction to the Theory of Forms	528
A.4. A Brief Introduction to Supersymmetry	532
A.5. A Brief Introduction to Supergravity	539
A.6. Glossary of Terms	544
A.7. Notation	560
References	562
Index	563