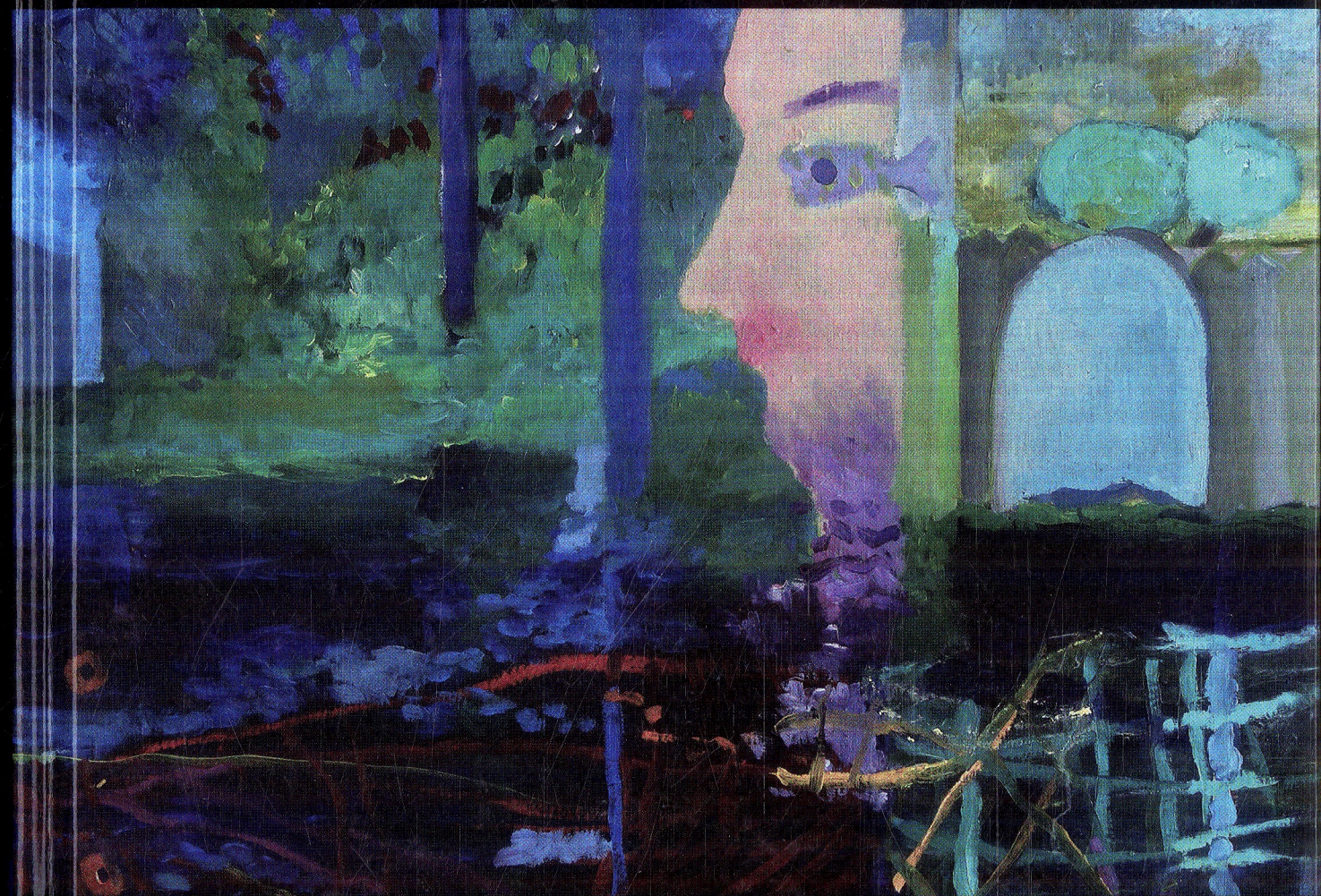


ADVANCED TOPICS IN
Quantum Field Theory

A Lecture Course



M. SHIFMAN

CAMBRIDGE

Contents

<i>Preface</i>	page xi
<i>References for the Preface</i>	xii
<i>Acknowledgments</i>	xiv
<i>Conventions, notation, useful general formulas, abbreviations</i>	xv
Introduction	1
References for the Introduction	7
 Part I Before supersymmetry	
1 Phases of gauge theories	11
1 Spontaneous symmetry breaking	12
2 Spontaneous breaking of gauge symmetries	19
3 Phases of Yang–Mills theories	25
4 Appendix: Basics of conformal invariance	34
References for Chapter 1	38
2 Kinks and domain walls	40
5 Kinks and domain walls (at the classical level)	41
6 Higher discrete symmetries and wall junctions	57
7 Domain walls antigravitate	66
8 Quantization of solitons (kink mass at one loop)	72
9 Charge fractionalization	81
References for Chapter 2	88
3 Vortices and flux tubes (strings)	90
10 Vortices and strings	91
11 Non-Abelian vortices or strings	99
12 Fermion zero modes	110
13 String-induced gravity	116
14 Appendix: Calculation of the orientational part of the world-sheet action for non-Abelian strings	120
References for Chapter 3	122

4 Monopoles and Skyrmions	123
15 Magnetic monopoles	124
16 Skyrmions	148
17 Appendix: Elements of group theory for $SU(N)$	167
References for Chapter 4	169
5 Instantons	171
18 Tunneling in non-Abelian Yang–Mills theory	172
19 Euclidean formulation of QCD	180
20 BPST instantons: general properties	183
21 Explicit form of the BPST instanton	187
22 Applications: Baryon number nonconservation at high energy	221
23 Instantons at high energies	229
24 Other ideas concerning baryon number violation	238
25 Appendices	240
References for Chapter 5	244
6 Isotropic (anti)ferromagnet: $O(3)$ sigma model and extensions, including $CP(N - 1)$	248
26 $O(3)$ sigma model	249
27 Extensions: $CP(N - 1)$ models	252
28 Asymptotic freedom in the $O(3)$ sigma model	256
29 Instantons in $CP(1)$	265
30 The Goldstone theorem in two dimensions	268
References for Chapter 6	272
7 False-vacuum decay and related topics	274
31 False-vacuum decay	275
32 False-vacuum decay: applications	283
References for Chapter 7	296
8 Chiral anomaly	298
33 Chiral anomaly in the Schwinger model	299
34 Anomalies in QCD and similar non-Abelian gauge theories	317
35 't Hooft matching and its physical implications	324
36 Scale anomaly	327
References for Chapter 8	329
9 Confinement in 4D gauge theories and models in lower dimensions	330
37 Confinement in non-Abelian gauge theories: dual Meissner effect	331
38 The 't Hooft limit and $1/N$ expansion	333
39 Abelian Higgs model in $1 + 1$ dimensions	357
40 $CP(N - 1)$ at large N	361
41 The 't Hooft model	367
42 Polyakov's confinement in $2 + 1$ dimensions	381
43 Appendix: Solving the $O(N)$ model at large N	392
References for Chapter 9	398

Part II Introduction to supersymmetry

10 Basics of supersymmetry with emphasis on gauge theories	403
44 Introduction	404
45 Spinors and spinorial notation	406
46 The Coleman–Mandula theorem	413
47 Superextension of the Poincaré algebra	415
48 Superspace and superfields	422
49 Superinvariant actions	428
50 R symmetries	445
51 Nonrenormalization theorem for F terms	446
52 Super-Higgs mechanism	450
53 Spontaneous breaking of supersymmetry	453
54 Goldstinos	456
55 Digression: Two-dimensional supersymmetry	459
56 Supersymmetric Yang–Mills theories	470
57 Supersymmetric gluodynamics	475
58 One-flavor supersymmetric QCD	477
59 Hypercurrent and anomalies	482
60 R parity	497
61 Extended supersymmetries in four dimensions	498
62 Instantons in supersymmetric Yang–Mills theories	506
63 Affleck–Dine–Seiberg superpotential	528
64 Novikov–Shifman–Vainshtein–Zakharov β function	531
65 The Witten index	533
66 Soft versus hard explicit violations of supersymmetry	538
67 Central charges	541
68 Long versus short supermultiplets	546
69 Appendices	547
References for Chapter 10	555
11 Supersymmetric solitons	560
70 Central charges in superalgebras	561
71 $\mathcal{N} = 1$: supersymmetric kinks	567
72 $\mathcal{N} = 2$: kinks in two-dimensional supersymmetric $CP(1)$ model	582
73 Domain walls	593
74 Vortices in $D = 3$ and flux tubes in $D = 4$	602
75 Critical monopoles	608
References for Chapter 11	613