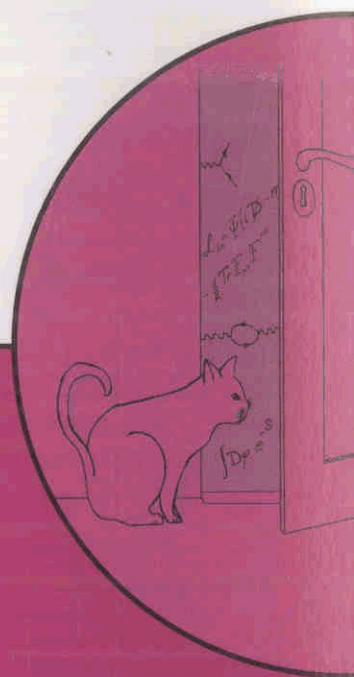


OXFORD MASTER SERIES IN STATISTICAL,  
COMPUTATIONAL, AND THEORETICAL PHYSICS

# A Modern Introduction to Quantum Field Theory

Michele Maggiore



oxford  
master series in condensed physics

# Contents

<b>Preface</b>	<b>xi</b>
<b>Notation</b>	<b>xii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Overview	1
1.2 Typical scales in high-energy physics	4
Further reading	11
Exercises	12
<b>2 Lorentz and Poincaré symmetries in QFT</b>	<b>13</b>
2.1 Lie groups	13
2.2 The Lorentz group	16
2.3 The Lorentz algebra	18
2.4 Tensor representations	20
2.4.1 Decomposition of Lorentz tensors under $SO(3)$	22
2.5 Spinorial representations	24
2.5.1 Spinors in non-relativistic quantum mechanics	24
2.5.2 Spinors in the relativistic theory	26
2.6 Field representations	29
2.6.1 Scalar fields	29
2.6.2 Weyl fields	31
2.6.3 Dirac fields	32
2.6.4 Majorana fields	33
2.6.5 Vector fields	34
2.7 The Poincaré group	34
2.7.1 Representation on fields	35
2.7.2 Representation on one-particle states	36
Summary of chapter	40
Further reading	41
Exercises	41
<b>3 Classical field theory</b>	<b>43</b>
3.1 The action principle	43
3.2 Noether's theorem	46
3.2.1 The energy-momentum tensor	49
3.3 Scalar fields	51
3.3.1 Real scalar fields; Klein-Gordon equation	51
3.3.2 Complex scalar field; $U(1)$ charge	53

3.4	Spinor fields	54
3.4.1	The Weyl equation; helicity	54
3.4.2	The Dirac equation	56
3.4.3	Chiral symmetry	62
3.4.4	Majorana mass	63
3.5	The electromagnetic field	65
3.5.1	Covariant form of the free Maxwell equations	65
3.5.2	Gauge invariance; radiation and Lorentz gauges	66
3.5.3	The energy-momentum tensor	67
3.5.4	Minimal and non-minimal coupling to matter	69
3.6	First quantization of relativistic wave equations	73
3.7	Solved problems	74
	<i>The fine structure of the hydrogen atom</i>	74
	<i>Relativistic energy levels in a magnetic field</i>	79
	Summary of chapter	80
	Exercises	81
<b>4</b>	<b>Quantization of free fields</b>	<b>83</b>
4.1	Scalar fields	83
4.1.1	Real scalar fields. Fock space	83
4.1.2	Complex scalar field; antiparticles	86
4.2	Spin 1/2 fields	88
4.2.1	Dirac field	88
4.2.2	Massless Weyl field	90
4.2.3	C, P, T	91
4.3	Electromagnetic field	96
4.3.1	Quantization in the radiation gauge	96
4.3.2	Covariant quantization	101
	Summary of chapter	105
	Exercises	106
<b>5</b>	<b>Perturbation theory and Feynman diagrams</b>	<b>109</b>
5.1	The S-matrix	109
5.2	The LSZ reduction formula	111
5.3	Setting up the perturbative expansion	116
5.4	The Feynman propagator	120
5.5	Wick's theorem and Feynman diagrams	122
5.5.1	A few very explicit computations	123
5.5.2	Loops and divergences	128
5.5.3	Summary of Feynman rules for a scalar field	131
5.5.4	Feynman rules for fermions and gauge bosons	132
5.6	Renormalization	135
5.7	Vacuum energy and the cosmological constant problem	141
5.8	The modern point of view on renormalizability	144
5.9	The running of coupling constants	146
	Summary of chapter	152
	Further reading	153
	Exercises	154

<b>6</b>	<b>Cross-sections and decay rates</b>	<b>155</b>
6.1	Relativistic and non-relativistic normalizations	155
6.2	Decay rates	156
6.3	Cross-sections	158
6.4	Two-body final states	160
6.5	Resonances and the Breit–Wigner distribution	163
6.6	Born approximation and non-relativistic scattering	167
6.7	Solved problems	171
	<i>Three-body kinematics and phase space</i>	171
	<i>Inelastic scattering of non-relativistic electrons on atoms</i>	173
	Summary of chapter	177
	Further reading	178
	Exercises	178
<b>7</b>	<b>Quantum electrodynamics</b>	<b>180</b>
7.1	The QED Lagrangian	180
7.2	One-loop divergences	183
7.3	Solved problems	186
	$e^+e^- \rightarrow \gamma \rightarrow \mu^+\mu^-$	186
	<i>Electromagnetic form factors</i>	188
	Summary of chapter	193
	Further reading	193
	Exercises	193
<b>8</b>	<b>The low-energy limit of the electroweak theory</b>	<b>195</b>
8.1	A four-fermion model	195
8.2	Charged and neutral currents in the Standard Model	197
8.3	Solved problems: weak decays	202
	$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$	202
	$\pi^+ \rightarrow l^+ \nu_l$	205
	<i>Isospin and flavor <math>SU(3)</math></i>	209
	$K^0 \rightarrow \pi^- l^+ \nu_l$	212
	Summary of chapter	216
	Further reading	217
	Exercises	217
<b>9</b>	<b>Path integral quantization</b>	<b>219</b>
9.1	Path integral formulation of quantum mechanics	220
9.2	Path integral quantization of scalar fields	224
9.3	Perturbative evaluation of the path integral	225
9.4	Euclidean formulation	228
9.5	QFT and critical phenomena	231
9.6	QFT at finite temperature	238
9.7	Solved problems	239
	<i>Instantons and tunneling</i>	239
	Summary of chapter	241
	Further reading	242

<b>10 Non-abelian gauge theories</b>	<b>243</b>
10.1 Non-abelian gauge transformations	243
10.2 Yang-Mills theory	246
10.3 QCD	248
10.4 Fields in the adjoint representation	250
Summary of chapter	252
Further reading	252
<b>11 Spontaneous symmetry breaking</b>	<b>253</b>
11.1 Degenerate vacua in QM and QFT	253
11.2 SSB of global symmetries and Goldstone bosons	256
11.3 Abelian gauge theories: SSB and superconductivity	259
11.4 Non-abelian gauge theories: the masses of $W^\pm$ and $Z^0$	262
Summary of chapter	264
Further reading	265
<b>12 Solutions to exercises</b>	<b>266</b>
12.1 Chapter 1	266
12.2 Chapter 2	267
12.3 Chapter 3	270
12.4 Chapter 4	272
12.5 Chapter 5	275
12.6 Chapter 6	276
12.7 Chapter 7	279
12.8 Chapter 8	281
<b>Bibliography</b>	<b>285</b>
<b>Index</b>	<b>287</b>