

Contents

Part I Basic Concepts, Introduction to QED, $g - 2$ in a Nutshell, General Properties and Tools

1	Introduction	3
	References	18
2	Quantum Field Theory and Quantum Electrodynamics	23
2.1	Quantum Field Theory Background	23
2.1.1	Concepts, Conventions and Notation	23
2.1.2	C, P, T and CPT	31
2.2	The Origin of Spin	36
2.3	Quantum Electrodynamics	47
2.3.1	Perturbation Expansion, Feynman Rules	50
2.3.2	Transition Matrix–Elements, Particle–Antiparticle Crossing	55
2.3.3	Cross Sections and Decay Rates	58
2.4	Regularization and Renormalization	60
2.4.1	The Structure of the Renormalization Procedure	60
2.4.2	Dimensional Regularization	64
2.5	Tools for the Evaluation of Feynman Integrals	71
2.5.1	$\epsilon = 4 - d$ Expansion, $\epsilon \rightarrow +0$	71
2.5.2	Bogolubov–Schwinger Parametrization	72
2.5.3	Feynman Parametric Representation	73
2.5.4	Euclidean Region, Wick–Rotations	73
2.5.5	The Origin of Analyticity	76
2.5.6	Scalar One–Loop Integrals	85
2.5.7	Tensor Integrals	88
2.6	One–Loop Renormalization	91
2.6.1	The Photon Propagator and the Photon Self–Energy	91
2.6.2	The Electron Self–Energy	101

2.6.3	Charge Renormalization	108
2.6.4	Dyson– and Weinberg–Power-Counting Theorems	117
2.6.5	The Running Charge and the Renormalization Group	120
2.6.6	Bremsstrahlung and the Bloch–Nordsieck Prescription	131
2.7	Pions in Scalar QED and Vacuum Polarization by Vector Mesons	143
2.8	Note on QCD: The Feynman Rules and the Renormalization Group	148
	References.	158
3	Lepton Magnetic Moments: Basics.	163
3.1	Equation of Motion for a Lepton in an External Field	163
3.2	Magnetic Moments and Electromagnetic Form Factors	168
3.2.1	Main Features: An Overview.	168
3.2.2	The Anomalous Magnetic Moment of the Electron.	193
3.2.3	The Anomalous Magnetic Moment of the Muon.	199
3.3	Structure of the Electromagnetic Vertex in the SM	201
3.4	Dipole Moments in the Non–Relativistic Limit	205
3.5	Projection Technique	207
3.6	Properties of the Form Factors	213
3.7	Dispersion Relations.	214
3.7.1	Dispersion Relations and the Vacuum Polarization	216
3.8	Dispersive Calculation of Feynman Diagrams	226
3.9	ζ –Values, Polylogarithms and Related Special Functions	236
	References.	241
 Part II A Detailed Account of the Theory, Outline of Concepts of the Experiment, Status and Perspectives		
4	Electromagnetic and Weak Radiative Corrections	249
4.1	$g - 2$ in Quantum Electrodynamics	249
4.1.1	One–Loop QED Contribution	251
4.1.2	Two–Loop QED Contribution	252
4.1.3	Three–Loop QED Contribution	255
4.1.4	Four–Loop QED Contribution.	261
4.1.5	Five–Loop QED Contribution	270
4.1.6	Four- and Five–Loop Analytic Results and Crosschecks	273
4.2	Weak Contributions	287
4.2.1	Weak One–Loop Effects	294
4.2.2	Weak Two–Loop Effects	295
4.2.3	Two–Loop Electroweak Contributions to a_e	334
	References.	337

5 Hadronic Effects	343
5.1 Hadronic Vacuum Polarization	345
5.1.1 Vacuum Polarization Effects and e^+e^- Data	345
5.1.2 Integrating the Experimental Data and Estimating the Error	356
5.1.3 The Cross-Section $e^+e^- \rightarrow$ Hadrons	360
5.1.4 Photon Vacuum Polarization and the Complex $\alpha_{QED}(s)$	364
5.1.5 $R(s)$ in Perturbative QCD	369
5.1.6 Non-Perturbative Effects, Operator Product Expansion	374
5.1.7 Leading Hadronic Contribution to $(g-2)$ of the Muon	377
5.1.8 Addendum I: The Hadronic Contribution to the Running Fine Structure Constant	392
5.1.9 Addendum II: The Hadronic Contribution to the Running $SU(2)_L$ Gauge Coupling	396
5.1.10 Addendum III: τ Spectral Functions versus e^+e^- Annihilation Data	400
5.1.11 A Minimal Model: VMD + sQED Resolving the τ versus e^+e^- Puzzle	402
5.1.12 Hadronic Higher Order Contributions	420
5.1.13 Next-to-Next Leading Order Hadronic Contributions	427
5.2 Hadronic Light-by-Light Scattering	429
5.2.1 Calculating the Hadronic LbL Contribution	434
5.2.2 Sketch on Hadronic Models	438
5.2.3 Pion-Exchange Contribution	445
5.2.4 The $\pi^0\gamma\gamma$ Transition Form Factor	450
5.2.5 Exchanges of Axial-Vector Mesons	487
5.2.6 Exchanges of Scalar Mesons	493
5.2.7 Tensor Exchanges	496
5.2.8 The Pion-Loop	497
5.2.9 The Quark-Loop	501
5.2.10 A Summary of Results	503
5.2.11 The Dispersive Approach	506
5.3 Lattice QCD	528
5.3.1 Lattice QCD Approach to HVP	535
5.3.2 Lattice QCD Approach to HLbL	550
References	558

6	The $g - 2$ Experiments	571
6.1	Overview on the Principle of the Experiment	571
6.2	Particle Dynamics	577
6.3	Magnetic Precession for Moving Particles	580
6.3.1	$g - 2$ Experiment and Magic Momentum	582
6.4	Theory: Production and Decay of Muons	587
6.5	Muon $g - 2$ Results	595
6.6	Ground State Hyperfine Structure of Muonium	597
6.7	Single Electron Dynamics and the Electron $g - 2$	599
6.8	The Upcoming Experiments: What Is New?	603
	References	606
7	Comparison Between Theory and Experiment and Future Perspectives	609
7.1	Experimental Results Confront Standard Theory	609
7.2	New Physics in $g - 2$	614
7.2.1	Generic Contributions from Physics Beyond the SM	621
7.2.2	Flavor Changing Processes	626
7.2.3	Anomalous Couplings	628
7.2.4	Two-Higgs Doublet Models	629
7.2.5	Supersymmetry	639
7.2.6	Dark Photon/Z and Axion Like Particles	661
7.3	Outlook on the Upcoming Experiments	664
7.4	Perspectives for the Future	665
	References	674
	Appendix A: List of Acronyms	683
	Index	687

The Anomalous Magnetic Moment of the Muon

Jegerlehner, F.

2017, XVIII, 693 p. 206 illus., 110 illus. in color.,

Hardcover

ISBN: 978-3-319-63575-0