

Contents

1	<i>Foreword</i>	7
	1.1 <i>Introduction</i>	7
	1.1.1 <i>Renormalization</i>	8
	1.2 <i>On-shell renormalization</i>	9
	1.2.1 <i>Z_2, Z_m from electron two-point-function</i>	9
	1.2.2 <i>Z_3, Z_ξ from photon two-point-function:</i>	10
	1.2.3 <i>Renormalization of the coupling strength Z_e</i>	12
	1.2.4 <i>Ward-Identity</i>	13
	1.3 <i>Scale dependence of the QED coupling</i>	14
	1.4 <i>Anomalous magnetic moment</i>	17
	1.4.1 <i>Extracting the magnetic moment</i>	17
2	<i>Non-abelian gauge invariance</i>	21
	2.1 <i>Massless Spin - One - Particles</i>	21
	2.1.1 <i>One more comment on unphysical gauge-invariance:</i>	23
	2.2 <i>Geometry of gauge-invariance</i>	24
	2.2.1 <i>The gauge field as a connection</i>	25
	2.3 <i>Kinetic energy term for A_μ</i>	26
	2.3.1 <i>The field strength</i>	26
	2.4 <i>Non-abelian symmetries</i>	27
	2.4.1 <i>Local symmetries</i>	29
	2.4.2 <i>Dual field strength tensor and Chern-Simmons current</i>	32
	2.5 <i>Pure Yang-Mills theory</i>	32
	2.5.1 <i>Equation of motion</i>	33
	2.5.2 <i>Currents and charges</i>	33
	2.5.3 <i>External currents are shady business</i>	34
	2.5.4 <i>Weinberg Witten theorem</i>	35

2.6	<i>Parallel transport in non-abelian gauge-theories</i>	36
2.7	<i>Euclidean space Yang Mills Theories</i>	36
2.7.1	<i>Winding number for a $SU(2)$ gauge theory</i>	38
3	<i>Quantizing Yang-Mills theories</i>	41
3.1	<i>Warm-Up</i>	41
3.2	<i>Faddeev-Popov procedure</i>	44
3.2.1	<i>Intermediate summary</i>	45
3.3	<i>BRST invariance</i>	46
3.3.1	<i>Warm-up: BRST invariance in QED</i>	47
3.4	<i>BRST invariance for non-abelian theories</i>	48
3.5	<i>Axial Gauges</i>	49
3.5.1	<i>Generalized Faddeev-Popov</i>	49
3.5.2	<i>Axial gauges and decoupling of ghosts</i>	50
3.6	<i>BRST and Slavnov operator</i>	51
3.6.1	<i>Set of physical states – Q-cohomology</i>	52
3.7	<i>S-matrix and BRST</i>	53
3.8	<i>BRS charge and Slavnov-Taylor Identities</i>	54
4	<i>Renormalization of non-abelian gauge theories</i>	57
4.1	<i>Feynman Rules</i>	57
4.2	<i>A tree-level QCD amplitude</i>	58
4.3	<i>One-loop divergences of non-abelian gauge theories</i>	60
4.4	<i>General considerations for renormalizing Yang-Mills theories</i>	61
4.5	<i>Vacuum polarization</i>	62
4.5.1	<i>Fermion bubble</i>	62
4.5.2	<i>Trilinear gluon bubble</i>	63
4.5.3	<i>Four-point gluon bubble</i>	65
4.5.4	<i>Ghost bubble</i>	66
4.6	<i>Renormalization at 1-loop</i>	67
4.7	<i>Running coupling in non-abelian gauge theories</i>	69
4.7.1	<i>Asymptotic freedom</i>	71
4.7.2	<i>Dimensional transmutation</i>	71
4.7.3	<i>Charge universality</i>	72
4.7.4	<i>Running of mass in QCD</i>	73

5	<i>Gravity as a gauge theory</i>	75
5.1	<i>Recipe:</i>	75
5.2	<i>Example: scalar-field $\phi(x)$</i>	76
5.3	<i>Dirac spinor and gravity</i>	79
5.4	<i>The Dirac Lagrangian with gravity</i>	80
5.5	<i>Action for gravity</i>	82
5.5.1	<i>Coupling gravity to matter</i>	84
5.5.2	<i>Relation to usual formulation:</i>	84
5.6	<i>Coupling gravity to matter</i>	86
5.7	<i>Gravity and gauge theories</i>	86
5.8	<i>Spin 2 fields and the QFT of gravity</i>	87
5.8.1	<i>Massive Spin 2 fields</i>	87
5.8.2	<i>Longitudinal fields and spin 1</i>	88
5.8.3	<i>Why are higher derivative terms problematic?</i>	89
5.8.4	<i>Longitudinal fields and spin 2</i>	90