

Index

- Abelian and non-Abelian 341 ff, 349
- absorption, photon 92, 151, 152
- acceleration operator 150
- action 5
- angular momentum
 - conservation law 12, 66, 352
 - density 11
 - density tensor 11, 65
 - Dirac field 67
 - free electromagnetic field Section 1.7, 28
 - multicomponent scalar field 14,
 - spin and orbital 14, 28, 56, 67
 - total for Dirac equation 56
 - total for Schrödinger field 71
- annihilation, *see* creation and annihilation operators
- antinormal ordering, *see* ordering of operators
- antiparticles 64, 69
- approximation
 - Born 131
 - Born-Markoff 134
 - nonrelativistic 176
 - rotating wave 122 ff, 160 ff, 187, 198, 285
 - rotating wave approximation at second level 137
- asymptotic
 - freedom 350
 - stationary states 198, 200
- atom-field Hamiltonian
 - Craig-Power model 258 ff
 - in cavity 119 ff, 149 ff
 - minimal coupling 88 ff, 103, 109, 241
 - multipolar coupling Section 4.4, 105, 108
 - pair of neutral atoms 267
 - two-level approximation 107 ff
- atomic
 - acceleration operator 150
 - diffraction by standing wave 156
 - eigenvalue spectrum (hydrogen) 89
 - momentum operator 149
 - stopping by laser beam 152
 - velocity operator 150
- atom-radiation ground state 128 ff, 160, 181 ff, 212, 242, 259
- bare
 - atom 115 ff, 128, 278 ff
 - atomic dynamics 128
 - field 115
 - states 126, 186
- Bessel functions 21, 25, 109, 316
- Bethe expression for Lamb shift 301, 359
- Bloch equations 148
- Bloch-Siegert shift 139
- Bogoliubov transformation 43
- Boltzmann statistics 47
- Born approximation, *see* approximation
- Born-Markoff approximation, *see* approximation
- Bose-Einstein
 - distribution 47
 - statistics 52
 - variance 48
- boson 61
- boundary conditions Section 1.11, 116 ff, 287
- canonical 4, 86, Section 2.1
- Casimir
 - force 301
 - Polder potential 270, 274, 303

364

cavity
 experiments 121, 148, 158
 finesse 122
 perfect Section 5.2
 quality (Q) factor 122

charge
 bare 347
 colour 349
 density 83
 effective 347
 fractional 341
 screened 347

cloud, virtual
 around an atom 116, 168, 212 ff, 251 ff,
 258 ff, 284, 356
 around an electron 170, 210 ff, 229 ff, 346 ff
 general properties Section 6.2
 in quantum chromodynamics 274
 of mesons 207 ff
 of phonons 179, 211
 shape 206 ff

coherent displacement operator 40, 162, 208
 coherent states 39 ff, 162
 collapses and revivals 128
 commutation relations
 Bose 61, 71
 Fermi 68, 71
 spin 107

complex field 60, 74
 Compton radius 55, 57, 347
 confinement 350
 conjugate moment
 electromagnetic field 10, 32, 86
 Klein-Gordon field 59

conservation laws
 angular momentum, *see* angular
 momentum
 Dirac field 65
 electromagnetic field 12
 Klein-Gordon field 59
 Schrödinger field 70

continuity equation
 Dirac equation 57
 Klein-Gordon equation 54
 Maxwell's equations 84
 Schrödinger equation 53

continuum limit 35, 38
 cooling
 laser 156, 158
 Sisyphus 156

Coulomb

Index

gauge, *see* gauge
 longitudinal energy 171

counterrotating terms 128

coupling constant
 electron-phonon 164, 179
 nucleon-meson 162, 169
 running 350
 two-level atom 108

covariance, manifest 9
 covariant derivative 340
 Craig-Power model 258 ff
 creation and annihilation operators 33 ff, 91,
 171

current density
 longitudinal and transverse 84
 probability 53, 83

cutoff frequency 106

damping 136, 146, 290

decay, spontaneous
 deviations from exponential 136, 158
 exponential rate 134 ff, 158, 290
 spectrum 137 ff
 time 136, 200

deflection by light 151

delta function
 longitudinal 15, 18
 transverse 15, 32

density matrix 47

Dicke model 108

diffraction, atomic 156

dipole, electric
 approximation 93, Section 4.5
 moment 104 ff, 319 ff

dipole force 156

dipole, magnetic moment 324

Dirac
 eigensolutions of equation 56
 equation 55 ff
 field Section 3.3
 field in terms of amplitudes 67
 Hamiltonian 56
 Lagrangian 64, 339
 matrices 56
 spinor 57

displacement
 field 97 ff
 operator 40 ff

dissipative
 force 152
 states 197

- divergence
 - infrared, *see* infrared divergence
 - perturbation theory 174, 187 ff
 - ultraviolet, *see* ultraviolet divergence
- dressed, *see* fluctuations, vacuum
- fluctuations, zero-point
 - electron 176, 179, 210
 - excited state 194, 206
 - operator 126, 143
 - photon 130, 158
 - relativistic source, Appendix G
 - source 116, 169
 - state 124 ff, 158, 194 ff, 212 ff, 282
 - Van Hove theory Section 6.6
- dressed atom
 - by real photons 116, 123 ff, 142 ff
 - by zero-point fluctuations 115, 168, 170, 281, 287
 - ground state 212 ff, 244 ff, 282 ff
- Einstein A-coefficient 133
- elastic spectrum in resonance fluorescence 147
- electric dipole, *see* dipole, electric
- electric field
 - around free electron 232
 - general 2 ff, *see* electromagnetic field,
 - longitudinal, transverse static dipole 218
- electromagnetic field
 - energy-momentum tensor 10
 - four-vector 3
 - in cavity 118 ff
 - plane wave expansion 21
 - spherical wave expansion 21
 - tensor 3
- electron, free 170 ff, 229 ff, 292
- electron-phonon
 - Hamiltonian 164 ff, 265
 - perturbed state 210 ff
 - screening potential 266
 - self-energy 178 ff
- electroweak interaction 78, 339, 341
- emission
 - one- and two-photon processes 92 ff
 - spontaneous, *see* decay, spontaneous
- energy density
 - and van der Waals forces Section 7.8
 - around free electron Section 7.4
 - around hydrogen atom Section 7.5, 7.6, 357
 - around two-level atom Section 7.2, 7.3
 - coarse-grained 205, 228
 - in Craig-Power model Section 7.7
 - in intermolecular potentials 274
 - of Dirac field 65
 - of scalar field 207 ff
- energy-momentum tensor
 - electromagnetic Section 1.6
 - Dirac field 65
 - general 207, Appendix H
 - Klein-Gordon field 59
 - Schrödinger field 70
- energy shift
 - and renormalization 136, 181
 - and van der Waals force 264 ff
 - atomic levels 158
 - atom-photon ground state 130, 181 ff
 - excited state 187
 - free electron 174
 - radiative, *see* radiative shift
- energy spectrum
 - Dirac field 69
 - hydrogen atom 89
 - Jaynes-Cummings model 124
 - Lee-Friedrichs model 192
 - relativistic free particle 54
- ensemble, statistical 46
- Euler-Lagrange equations
 - Dirac field 64
 - general 4, 352
 - Klein-Gordon field 59
 - Schrödinger field 70, 82
- exchange of virtual quanta 263 ff
- expansion
 - and boundary conditions 22 ff
 - normal modes 118
 - plane waves 21
 - spherical waves 21, 108
- exponential decay
 - deviations from 136
 - rate, *see* decay, spontaneous
- far-zone
 - hydrogen atom 251 ff
 - two-level atom 216 ff
 - van der Waals potential 271
- Fermi-Dirac statistics 52
- Feynman diagrams 93, 174, 264, 266, 346
- fine structure constant 169, 176
- flavour 341, 349
- fluctuations, *see* vacuum, zero-point, dressed atom

366

fluorescence
 dressed atoms 142
 elastic components 147
 inelastic components 147
 resonance 116, 140 ff, 158
 Fock space 37, 72
 force
 Casimir 274, 301
 dipole 156
 dissipative 151
 operator 150 ff
 radiative 148 ff
 reactive 156
 van der Waals 109, 272, 274, 287 ff, 301 ff
 Yukawa 265
 fractional electric charge, *see* charge,
 fractional
 Fröhlich polaron 164 ff, 168, 178, 186, 210 ff
 gauge
 Abelian and non-Abelian theory 341 ff,
 349
 Coulomb 8 ff, 31 ff, 86 ff
 field 77, 340
 fixing 7
 invariance Section 3.5, 80, Appendix F
 Lorentz 8, 84
 transformation, global 73, 340
 transformation, infinitesimal 75
 transformation, local 7, 73, 77, 340
 transverse, *see* gauge, Coulomb
 generalized coordinates 9, 86
 generalized functions 325
 Glauber transformation 31
 gluon 170, 342, 349 ff
 group
 SU(3) 342, 349
 U(1) 340
 half-dressed, *see* partially dressed
 Hamiltonian
 atom-field 88 ff, 119 ff, 160, *see* minimal
 coupling, multipolar, Hamiltonian
 density
 atom-pointer 278 ff
 canonical 86
 effective 111, 155, 258
 Fröhlich polaron 164
 hydrogen 89
 Jaynes-Cummings 121 ff
 Lee-Friedrichs 187

Index

relativistic matter field 345
 rotating wave approximation 122 ff, 187,
 285
 static source-scalar field 162
 two-level atom 107 ff, 198, 212 ff, 278 ff
 Hamiltonian density
 Dirac field 65 ff
 electromagnetic field Section 1.5, 85 ff
 Klein-Gordon field 59 ff
 Schrödinger field 70, 86 ff
 harmonic oscillator, damped 290
 Hartree solutions 91
 Hartree-Fock solutions 91
 Heisenberg uncertainty relations 58, 139,
 167, 276
 Helmholtz equation 19
 high-precision tests of QED 338
 hydrogen atom 89, 240 ff, 356 ff, 359 ff
 image charges 119
 inelastic spectrum in resonance fluorescence
 147
 infrared divergence 174, 177
 instantaneous propagation 84
 interaction Hamiltonian, *see* Hamiltonian
 ionized states 90
 isospin 75
 Jaynes-Cummings
 Hamiltonian 121 ff
 model, squeezing 158
 Klein-Gordon
 complex field 60, 74
 density operator 61 ff
 equation 54
 field Section 3.2
 field in terms of amplitudes 59
 free-field Lagrangian 58
 Hamiltonian 61 ff
 real field 61
 Lagrangian density
 atom-photon 82 ff
 Dirac field 64 ff, 339 ff, 356
 electromagnetic field Section 1.2
 Klein-Gordon field 58 ff
 quantum chromodynamics 341 ff
 Schrödinger field 70
 Lamb shift 101, 136, 139, 140, 146, 181, 287,
 292 ff, Appendix J
 Lee-Friedrichs Hamiltonian 187

- level shift, *see* energy shift
- localizability
 - Dirac particle 57
 - Klein-Gordon particle 55, 57
 - photon Section 2.6, 50
- longitudinal
 - Coulomb energy 171
 - current 84
 - electric field 86, 249
 - delta-tensor 15
 - vector field Section 1.8
- Lorentz
 - covariance 5
 - gauge, *see* gauge
 - invariance 84
 - transformation Section 1.3
- Lorentzian spectrum 139

- magnetic dipole, *see* dipole, magnetic
- magnetic field
 - around free electron 232
 - general 2 ff, *see* electromagnetic field, transverse
- magnetization field 321
- Markoffian equation 132 ff, 158, *see* approximation
- mass
 - bare 177, 179
 - dressed 176, 179
 - effective 176
 - photon 341
 - renormalization, *see* renormalization
- Maxwell
 - equations Section 1.1
 - stress tensor 12
- Maxwell-Lorentz equations 83 ff
- measurement
 - bare atom 280 ff
 - dressed atom 280 ff
 - long and short 283, 286
 - quantum theory 276 ff
- measuring apparatus 277 ff
- meson 161 ff, 206 ff, 264 ff
- micromaser 122, 128, 158
- minimal coupling 88, Section 4.3, 103 ff, 133, 161, 170 ff, 181, 230 ff, 288 ff
- Mollow triplet 147
- momentum of the field
 - angular, *see* angular momentum
 - electromagnetic 10 ff, 151
 - Schrödinger 70
- multipolar
 - expansion of electromagnetic field 21, 36, Appendix A
 - form of electron field 95 ff
 - form of velocity field 99
 - Hamiltonian Section 4.4, 119 ff, 133, 149, 161, 181, 212 ff
- near-zone
 - hydrogen atom 251 ff
 - two-level atom 216 ff
 - van der Waals potential 271
- negative energy states 55, 57, 63
- neutron 168
- Noether's theorem 13, 74, 80
- noise, quantum 44
- nonclassical states of the field 51
- nonperturbative methods 142, 170, 188
- nonretarded effects 220, 257
- normal
 - modes 117 ff
 - ordering, *see* ordering of operators
- nucleon 161 ff, 169, 179, 206 ff
- number
 - operator 37
 - state 39
- one- and two-photon
 - absorption and emission 92 ff
 - states 231
- orbital angular momentum 14, 28, 56, 67
- ordering of operators 171, 290 ff, 298, 305 ff
- pair creation and annihilation 346
- partially dressed 284, 309
- periodic boundary conditions 25 ff
- perturbation theory 111, 129, 141 ff, 160, 165, 170, 172 ff, 178 ff, 187 ff, 203, 213 ff, 230 ff, 258 ff, 266, Appendix C, 357
- phonon 164 ff, 168, 179, 210 ff, 266
- photon
 - absorption and emission processes 92 ff, 152, 151
 - as elementary excitations 101
 - creation and annihilation 37
 - definition 37
 - density operator 274
 - dressed 130, 158
 - localizability Section 2.6, 50
 - mass term 341
 - number operator 37
 - virtual 161, 168 ff, 212 ff

368

Poincaré transformation 353
 pointer Section 8.1
 Poisson
 distribution 41
 equation 84 ff, 212
 polarizability 112, 220, 257 ff, 271 ff, 301 ff, 332
 polarization
 circular 29
 electric and magnetic 95 ff, 183 ff,
 Appendix B
 sum rules 33
 vacuum 347
 vectors 19, 26 ff, 107
 polaron, *see* Fröhlich polaron
 pole approximation 197
 position operator 48, 53, 55, 57
 Power-Zienau transformation 94 ff
 Poynting vector 12
 probability density 53 ff, 61, 63, 69
 projection operator 197, 327, *see*
 perturbation theory
 propagator of the electromagnetic field 35
 proton 168
 pseudospin operators 107

 quadrupole electric moment 319
 quadrupole magnetic moment 324
 quantization
 canonical 32
 in Coulomb gauge 31, 36
 second 61 ff, 68, 71 ff, 79, 89
 quantum
 chromodynamics 78, 274, 339 ff, 349 ff
 theory of measurement 276 ff
 quarks 170, 341 ff, 349 ff

 Rabi
 frequency 128 ff, 286
 oscillations 128 ff, 148, 158
 vacuum splitting 148
 radiation reaction 83, 288 ff
 radiative forces on atoms Section 5.6
 radiative shift 130, 291 ff, 359 ff
 Rayleigh-Schrödinger perturbation theory,
 Appendix C, *see* perturbation theory
 reactive force 156
 recoil 151, 168, 265
 refractive index 294
 relativistic wave equation 54 ff, 79
 renormalization 136, 177, 179, 181, 203, 300

Index

reservoir 47
 resolvent 195 ff, 203
 resonance fluorescence 116, Section 5.5, 158
 retardation effects 254
 retarded potentials 84
 Röntgen force 149
 Rydberg states 90, 113

 scalar
 electromagnetic potential 3
 field, *see* Klein-Gordon
 Lorentz 6
 Schrödinger
 charge 78, 317 ff
 equation 53
 field Section 3.4, 82 ff, 317 ff, 339
 field in terms of amplitudes 71
 Hamiltonian 70, 85 ff
 Lagrangian 70, 76 ff, 82
 velocity field 99, 320 ff
 screened Coulomb potential 211, 266, 347
 screening and antiscreening 350
 selection rules 93
 self-energy Section 6.3, 6.4
 self-interaction 343, 349
 self-reaction field 287
 shift
 energy, *see* energy shift
 Lamb, *see* Lamb shift
 operator 162
 radiative, *see* radiative shift
 source
 point 88, 207
 spherical 163
 spectrum of light
 in resonance fluorescence 145 ff
 in spontaneous decay 137
 spherical
 Bessel functions, *see* Bessel functions
 harmonics 249 ff, 311 ff, 316
 spin 14, 28, 56, 67
 spinors 57, 67
 spontaneous emission, *see* decay,
 spontaneous
 squeezed states Section 2.4, 51, 158
 state
 asymptotic stationary 198, 200
 coherent 40 ff, 162
 dissipative 197
 ionized 90
 nonclassical 51

- state *continued*
 number 39
 one- and two-photon 231
 squeezed Section 2.4, 51, 158
 thermal Section 2.5
 vacuum 37
- stress tensor
 canonical 352
 Maxwell 12
- strong force 162, 170, 265, 341
- sub-Poissonian 46
- sum rules
 hydrogen, Appendix D
 Thomas-Reiche-Kuhn 186, 295, 330
 vector spherical harmonics 316
- superconductivity 266, 274
- super-Poissonian 46
- tensor
 antisymmetric 11, 222, 353
 rank 6, 11
 symmetric 10, 353
 traceless 10
- thermal states Section 2.5
- thermofield analysis 46
- Thomas-Reiche-Kuhn, *see* sum rule
- transformation, *see* Bogoliubov, gauge, Glauber, Lorentz, Poincaré, Power-Zienau, unitary
- Transverse
 current 84
 delta-tensor 15
 electric and magnetic fields 16
 vector field Section 1.8
- two-level atom 106, 121 ff, 160, 168, 181 ff, 186 ff, 198 ff, 212 ff, 278 ff, 288 ff
- two-photon processes 92, 103, 168, 216
- ultraviolet divergence 176
- unitary transformation 42, 43, 74, 94 ff, 113, 153, 162, 180, 182
- unit systems 2, Appendix E
- vacuum
 fluctuations 204, *see* fluctuations, zero-point, dressed atom
 general 51, 351
 polarization 347, 349
 quantum chromodynamics 350
 radiative effects Section 8.2
 squeezed 46
- state 37
- van der Waals forces 109, 272, 274, 287 ff, 301 ff, *see* energy density, energy shift far zone, near zone
- Van Hove dressed states Section 6.6
- variance
 electric field 38, 39, 42, 44
 photon number 41, 45, 48
 pointer position 282
- vector
 potential 3
 spherical harmonics 21, 24, 244, 313 ff, 315
- velocity operator 99, 150, 319 ff
- virtual
 cloud Section 6.2, 178, 202, 206 ff, 229, 251 ff, 258 ff, 274, 284, 287, 301, 307, 347, *see* cloud
 electrons and positrons 346 ff
 gluons 349
 mesons 164, 169, 210, 265
 phonons 165, 170, 179, 210, 266
 photons 116, 168, 170 ff, 212 ff, 237 ff, 284, 346
 quanta Section 6.1, 7.1, 263
 quarks and antiquarks 349
 transitions between bare levels 281
- wave
 electric and magnetic multipole 21
 equation Section 3.1, 79
 polarized 26, 29
 standing 24, 152, 156
 travelling 24, 26, 152, 156
- wavefunction
 collapse 278
 hydrogenic 90, 241
 nonrelativistic 53
 relativistic 54 ff
- Wigner-Weisskopf decay law 134
- Yukawa
 force, *see* force
 potential 266
- Zeno effect 136
- zero-point, *see* dressed atom, fluctuations, vacuum
 effect on bound electron 293
 energy of mesons 209
 reduced quantum noise 44