

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

Index

- Q^α_β
 - scalar electrodynamics, 412
 - Yang-Mills theory, 365
- $Q_{\alpha\beta}$
 - gravity, 368
- R -summed action
 - and acceleration of the universe, 132
- R -summed form
 - dimensionally invariant, 131
- R -summed form of propagator, 130
- R -summed heat kernel
 - and effective action, 132
- S_{int} , 297
- $\hat{\Gamma}[\sigma[\varphi_*; \bar{\varphi}]; \varphi_*]$, 290
- Γ -function, integral representation, 208
- $\underline{K}$ definition, 377
- Q^α_β
 - definition, 362
- β -function
 - definition, 319
 - determined by simple pole, 320
 - Yang-Mills theory, 407
- δ -function, *see* Dirac δ -distribution
- periodic, 213
- δ -function, defined, 270
- ϵ in dimensional regularization, 196
- $\gamma^{\alpha\beta}$
 - definition, 360
 - gravity, 367
 - scalar electrodynamics, 410
 - Yang-Mills theory, 364
- γ_5 matrix, 146, 232
- $\gamma_{\alpha\beta}$
 - definition, 360
 - gravity, 367
 - interpretation, 361
 - scalar electrodynamics, 410
 - Yang-Mills theory, 364
- $\hbar$ expansion, 296
- $\langle \cdots \rangle$ defined, 281, 290
- $\langle \cdots \rangle_G$ defined, 297
- $\bar{\varphi}$, 281, 289
- $\tilde{\delta}$ -function, defined, 271
- ζ -function, 197
 - ζ -function regularization, 196–199
 - conformal anomaly, 219
 - $\zeta(0)$ related to pole in dimensional regularization, 199
- n -bein, 221
 - covariant derivative, 223
- s -wave approximation, 180
- divp** defined, 194
- a-type numbers, 242
- abelianization, 421
- accelerated detector
 - derivation of temperature observed, 92
 - Fulling-Davies-Unruh effect, 126
 - in Minkowski spacetime, 152
 - interaction with quantized field, 92
- accelerated detector in Minkowski spacetime, 91
 - Rindler coordinates, 91
 - Unruh detector, 91
- accelerated proton
 - decays by weak-interaction, 92
- Acceleration radiation
 - insensitive to Planck scale physics, 181
- acceleration radiation
 - from Page approximation in Minkowski spacetime, 125
- action, 2, 37
- action functional
 - N scalar fields, 302
 - $O(N)$ model, 322
 - electromagnetism, 350
 - gravitational, 302
 - gravity, 352
 - non-Abelian gauge theory, 352
 - non-linear sigma model, 285
 - scalar electrodynamics, 408
 - scalar fields, 186
 - under field redefinitions, 283
 - Yang-Mills theory, quadratic order, 401
- adiabatic bases
 - any one can be used to “label” and evolve the set of physical expectation values, 97
- adiabatic condition, 96
 - and Hadamard condition, 89

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

446

Index

- adiabatic condition (cont.)
 - determines unique adiabatic series that is generally not convergent, 96
- adiabatic expansion, *see* adiabatic series
 - of Green function in Riemann normal coordinate local momentum space, 139
- adiabatic regularization, 94
 - adiabatic order, 95
 - definition of, 103
 - energy-momentum tensor, 94
 - of field squared, 104
 - particle number in expanding universe, 94
 - slowness parameter, 95
 - trace anomaly, conformal anomaly, 106
 - trace of energy-momentum tensor, 105
- adiabatic series
 - a second iterative derivation, 100
 - explicit expressions to fourth order, 101
 - of Feynman Green function in general spacetime, 111
 - of field squared, 104
 - of inhomogeneous Green function in general spacetime, 111
- adiabatic series in closed form
 - to any finite order, 99
- adiabatic subtraction, *see* adiabatic regularization
- adiabatic vacuum
 - definition and non-uniqueness, 96
- adiabatic vacuum state: not unique—examples
 - from exact solution, 96
- adiabatic vacuum states
 - in general curved spacetime, 89
- adjoint representation, 228
- adjoint representation, Lie algebra
 - generators, 404
- adjoint spinor, 245
- algebraic quantum field theory
 - in curved spacetime, 90
- algebraic quantum field theory
 - interacting fields in curved spacetime, 91
- angular momentum, 9
 - total including spin, 32, 33
- annihilation operator, 15
- anticommutation relations, 28
- anticommuting numbers, *see* Grassmann numbers
- antiparticle, 29
- antiperiodic boundary conditions, 211
- area of event horizon
 - Kerr black hole, 173
 - relation with entropy, 174
- asymptotic form
 - and conserved Wronskian, 51
 - early times, 49, 51
 - late times, 51
- asymptotic freedom, 407
- asymptotically static cosmological spacetime, 47
- auxiliary field, 398, 400
- axial anomaly, 257–263
- axial current, 258
 - divergence related to heat kernel coefficient, 260
- axial transformation, 257
- axial vector or chiral current
 - and chiral symmetry, 146
 - conserved for massless unquantized Dirac field, 146
- back reaction to black hole evaporation, 178
- background field, 287
- background-field gauge
 - gravity, 368
 - Yang-Mills theory, 365
- Bardeen metric, 179
- bare coupling constants, 302
 - dimensions, 303
 - in terms of renormalized ones, 318
 - independent of renormalization length, 319
- Berezin integration, 242–245
 - change of variable, 244
- biscalar, 270
- bispinor Green function, 148
- black hole luminosity
 - massless scalars, 178
 - neutrinos, photons, and gravitons, 178
- Bogolubov transformation, 47, 55, 152
 - finding coefficients in spherical gravitational collapse, 166
 - in gravitational collapse spacetime, 164
 - relating coefficients in gravitational collapse of rotating body, 172
 - relating coefficients in Schwarzschild black hole, 167
- Borchers' theorem, 284
- boundary conditions
 - relation to inequivalent spin structures, 240
- Boyer-Lindquist coordinates, 154
- Bunch-Davies vacuum
 - from conformal vacuum, 72
- c-type numbers, 242
- canonical commutation relations, 2, 49, 50, 276
- canonical commutators, 6
- canonical momentum, Dirac field, 147

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)*Index*

447

- canonical momentum, field, 276
- canonical quantization, 5, 6
 - charged scalar field, 25
- Casimir effect, 19, 21
 - complex scalar field, 215
 - confirmed experimentally, 24
- Casimir invariant, 404
- centre of algebra, 232
- charge, 26
 - conserved, 40
 - electron, positron, 31
- charge conjugate spinor, 237
- Chern-Simons action, 266
- Chern-Simons theory, 263–267
- chiral anomaly, *see* axial anomaly
- chiral current anomaly, 144–151
 - of Dirac field in curved spacetime, 94
- chiral current anomaly derived by adiabatic subtraction, 147–151
- chiral spinors, 236
- chiral symmetry
 - and axial vector or chiral current, 146
- chiral transformation, 257
- chirality, 236
- Christoffel connection
 - gravity, 366
 - non-linear sigma model, 332
 - scalar electrodynamics, 409
 - vanishes for Yang-Mills theory, 363
- chronological product, 278
- classical Schwarzschild and Kerr black holes, 153–162
- Clifford algebra, 229
 - non-trivial center in odd dimensions, 232
- closed algebra, 354
- closed timelike curves
 - and quantum field theory, 182
 - and traversable wormholes, 182
- closed-time-path functional integral
 - and in-in formalism, 183
 - in curved spacetime, 182
- CMB, 65
 - temperature anisotropies, 75
- Coleman-Weinberg effective potential, 325
- complex conjugation of Grassmann numbers, 246
- complex scalar field
 - Cartesian form, 408
 - complex form, 408
 - polar form, 408
- condensed notation, 186–188, 270–271
 - gravity, 357
 - Yang-Mills theory, 355
- conformal vacuum
 - reduces to Bunch-Davies vacuum in de Sitter, 71
- conformal anomaly, *see* trace anomaly
 - functional integral derivation, 216–221
 - link to functional measure, 216
- conformal invariance, 42
 - action, 44
 - and trace anomaly, 42
 - and vanishing trace of energy-momentum tensor, 42
- conformal invariance of Dirac equation
 - requires masslessness, 251
- conformal Killing vector field, 108
- conformal time, 52
- conformal transformation
 - n spacetime dimensions, 216
 - infinitesimal, 42
 - spinor field, 250–251
- conformal vacuum
 - used to derive Bunch-Davies vacuum in de Sitter, 72
- conformally-invariant massless scalar field
 - proof of conformal invariance, 56
- conjugate spinor and the ϵ -matrix in curved spacetime, 144
- connection
 - torsion-free condition, 223
 - Vilkovisky-DeWitt, 378
- connection one-form, 223
- constant of the motion, 155
- constants of the motion
 - Kerr, 159
 - Schwarzschild, 155
- continuum limit, 19
- conventions, 43
- coordinate basis one-form, field space, 360
- coordinate transformation
 - infinitesimal, 352
 - metric tensor under, 352
- cosmic time, 47
- Coulomb gauge, 349
- Coulomb potential, 348
- counterterms, 318
 - expressed as sum of poles, 319
 - interacting scalar field theory, 303
 - loop expansion, 304
 - scalar field, one-loop order, 305
 - two-loop order, 317
- covariant derivative, 26, 27, 37
- covariant derivative of a spinor, 144, 228
- covariant Taylor expansion
 - derivation, 344–345
 - for action functional, 287
 - recursive relation for action functional, 332

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

448

Index

- covariantly constant gauge field, 403
- creation and annihilation operators
 - in spacetime of body collapsing to form a black hole, 162, 164
- creation of particles, 47
 - absence of, 47
 - by black holes, 36
 - by expanding universe, 36
 - inflation, primordial fluctuations and CMB, 36
- current, 13, 25, 40
 - electron, positron, 31
- curvature conventions, 43
- curvature two-form, 224
- curved spacetime γ -matrices
 - and vierbein, 145
- de Sitter spacetime, 48, 64–72
 - 10 parameter de Sitter group, 66
 - Bunch-Davies vacuum, 71
 - Bunch-Davies vacuum state, 65
 - conformal vacuum and Bunch-Davies vacuum, 65
 - conformal vacuum and Bunch-Davies vacuum agree, 72
 - high frequency asymptotic form of scalar field, 69
 - Hubble horizon, 68
 - infrared divergence, 72
 - isometries, 65
 - scalar field, 67
- DeWitt effective action
 - gauge theories, 397
 - Landau-DeWitt gauge, 399
- DeWitt metric, 365
- dimensional regularization, 112, 195–196, 303
- Dirac δ -distribution, 186, 270
- Dirac delta function, 40
- Dirac equation, 28
 - n -bein form, 227
 - covariant derivative of a spinor, 144
 - gamma matrices in curved spacetime, 144
 - in curved spacetime, 144
 - Lagrangian in curved spacetime, 145
 - transformation, 34
 - Weyl spinor, 236
- Dirac field, 27
 - covariant derivative, 228
- Dirac field in curved spacetime, 94, 144–149
 - affine connection and vierbein, 145
 - vector current, 145
- Dirac matrices
 - curved spacetime, 144
 - Majorana representation, 237
 - Weyl representation, 234
- dual electromagnetic field tensor, 207
- effective action
 - and acceleration of the universe, 132
 - and derivatives of curvature tensors, 132
 - definition, 281
 - dependence on field parameterization in usual definition, 286
 - DeWitt definition, 293, 294
 - DeWitt definition, loop expansion, 302
 - expansion to two-loop order, 301
 - from R -summed heat kernel, 132
 - functional integral representation, 282, 290
 - gauge invariance, 390–393
 - gauge theories, 392
 - gauge theories, definition, 390
 - general definition, 290
 - imaginary part and particle creation, 133
 - independence of gauge conditions, 393–395
 - loop expansion, 298–302
 - loop expansion, gauge theories, 395–399
 - non-perturbative transition to constant Ricci scalar curvature, 132
 - one-loop order, 283
 - one-loop, gauge theory, 400
 - two-loop expression, 301
 - two-loop order, divergent part, 316
 - two-loop order, interacting scalar field, 307
 - zeroth order term, 296
- effective Lagrangian
 - related to effective action, 205
- effective potential
 - $O(N)$ model, 324
 - curved spacetime, 328–331
 - exact result, 327
 - in terms of effective action, 322
 - in terms of one-loop effective action, 191
 - scalar electrodynamics, 417–419
- Einstein equations
 - needs in-in expectation values, 182
- energy-momentum tensor
 - by Hadamard regularization, 120
 - by point splitting time-ordered product, 141
 - canonical, 8, 38
 - conserved result by modified Hadamard regularization, 121
 - difference between vacuum states of Schwarzschild black hole spacetime, 176
 - from trace anomaly in R-W universes for conformally invariant free fields, 108, 110
 - of classical conformally invariant scalar field, 120
 - of scalar field, 45

- other approximations, 129
- Page approximation to, 126
- physical quantities quadratic in fields, 93
- sign convention, 39
- symmetric, 9, 39, 45
- trace anomaly, 42, 93, 106, 142
- trace anomaly by Hadamard regularization, 121
- trace anomaly for higher spin, 107
- trace anomaly for spin-0, 114
- trace anomaly for spin-1/2 and spin-1, 114
- trace anomaly in general curved spacetime, 107
- trace anomaly, covariant form of, 107, 113
- energy-momentum tensor with Hawking flux, 174–178
- energy-momentum vector, 9
- Dirac field, 31
- entropy
 - Kerr black hole, 173
- entropy and generalized second law, 172–174
- entropy of black hole relation to area, 174
- equation of motion
 - for transition amplitude, 279, 287
- equation of motion, for field operators, 275
- equivalence class
 - gauge fields, 359
- Euclidean Green function, 122
- Euler characteristic, 335
- event horizon
 - Kerr solution, 154
- evolution operator, 4
- exact solution
 - black body radiation, 64
 - particle creation, 63
- exterior derivative, 223
- external source, 277

- Faddeev-Popov ansatz, 389
- Faddeev-Popov ghosts, 396
- Feynman diagrams, 301
- Feynman Green function
 - for Dirac field in curved spacetime, 147, 150
 - in terms of time ordered product, 186
 - scalar fields, 186
 - spinor field, 253
- Feynman path integral
 - for transition amplitude, 280
- Feynman propagator, *see* Feynman Green function
- field redefinitions, 285
- field space, 285
- field space connection, 286
 - scalar electrodynamics, 410, 411
- field space displacement, 360
- field space line element, 361
 - Kaluza-Klein form, 389
 - scalar electrodynamics, 408
- field space metric, 286, 360
 - gravity, 365
 - non-linear sigma model, 332
 - scalar electrodynamics, 409
 - Yang-Mills theory, 363
- field strength tensor
 - electromagnetism, 350
 - in terms of electric and magnetic fields, 207
 - non-Abelian gauge theory, 351
- first law of thermodynamics
 - Kerr black hole, 173
- Fock representation, 16
- Fourier series, 212
- Fulling, Davies, Unruh effect
 - from Page approximation, 125
- functional derivative, 6
- functional derivative, defined, 271
- functional integral, *see* Feynman path integral
- functional integral measure
 - scalar electrodynamics, 412–413

- gamma matrices, 27, 227, *see* Dirac matrices
- gauge conditions, 348, 361
- gauge coupling constant, 351
- gauge coupling constant renormalization, 406
- gauge covariant derivative, 401
- gauge covariant derivative operator, 364
- gauge field
 - constant electromagnetic field, 200
- gauge field renormalization, 406
- gauge group
 - electromagnetism, 349
 - non-Abelian, 349
- gauge invariance
 - classical action, 353
 - electromagnetism, 348, 351
- gauge transformation, 26
 - electromagnetism, 350
 - general form, 352
 - generators, 352
 - local, 352
 - non-Abelian gauge theory, 351
 - rigid, 352
 - scalar electrodynamics, 408
- gauge transformation generators
 - scalar electrodynamics, 409
- gauge-fixing conditions, 361
- gauge-fixing term, 349
- Gauss-Bonnet invariant, 114

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

450

Index

- Gaussian approximation, 93
 - to Feynman propagator, 116
 - and Page approximation, 117
- exact in Einstein static universe, good approximation in de Sitter universe, 116
- non-perturbative, 117
- relation to proper-time and heat kernel series, 117
- general relativity, 36
- generalized ζ -function, 197
- generalized second law of thermodynamics, 174
- generating functional
 - $W[J]$ defined, 281
 - $Z[J; \varphi_*]$ defined, 337
 - $W[J; \varphi_*]$, 289
 - $W[J; \varphi_*]$ contains only connected diagrams, 340–342
 - relation of $W[J; \varphi_*]$ to $Z[J; \varphi_*]$, 337
- generating functional $Z[J; \varphi_*]$
 - sum of all vacuum diagrams, 338
- generator, 10, 25, 33
 - of infinitesimal isometry and field transformation, 39
 - when conserved in curved spacetime, 40
- generators
 - Lie algebra, 351
- generators of gauge transformations
 - gravity, 357
 - Yang-Mills theory, 356
- geodetic interval, 286
 - in Riemann normal coordinates, 331
- Grassmann numbers, 242–245
- gravity with dynamical preferred frame, 180
- gray body spectrum
 - of radiation from Kerr black hole, 172
 - Schwarzschild black hole, 169
 - wave packets, 171
- Green function
 - divergent parts of products, 309–315
 - inverse of differential operator, 187
 - manifestly covariant form in configuration space from Riemann normal coordinate momentum space, 143
 - proper time series from normal coordinate momentum space expansion, 142
 - proper-time adiabatic series coefficients, 111
 - relation to heat kernel, 308
- Green function bispinor
 - momentum space expression in Riemann normal coordinates, 149
- Green function in momentum space
 - setting boundary conditions by displacing poles, 140
- Gribov ambiguity, 363
- Hadamard condition
 - and adiabatic condition, 89
- Hadamard form
 - change with invariant Planck length, 180
- Hadamard Green functions in different vacuum states, 176
- Hadamard regularization, 118
 - coincidence limit of point-split result, 120
- Hadamard Green function, 119
- Hadamard-regularized Green function, 120
- of energy-momentum tensor, 120
- point-splitting, 120
- trace anomaly, 121
- Hadamard series, 119
- Hamiltonian
 - particle in constant electromagnetic field, 200
- Hawking radiation
 - from acceleration radiation in 6-dimension, 181
 - insensitive to Planck scale physics, 181
 - nonlinear realization of Lorentz group, 180
 - trans-Planckian frequencies, 180
- Hawking temperature
 - Kerr black hole, 172
 - Schwarzschild black hole, 169
- heat kernel, 193–194, 198
 - R -summed form, 130
 - asymptotic expansion, 193, 199
 - coefficients, 194
 - constant electromagnetic field, 201–205
 - constant gauge field, 211–213
 - for $O(N)$ model, 322
 - free scalar field, 204
 - series coefficients, 111
- Heisenberg picture, 4
- homomorphisms and spin structure, 241
- Hubble radius, 68
- Hubble scale, 68
- in-in formalism
 - and higher-order correlations in cosmology, 183
- in-out to in-in amplitudes
 - by Bogolubov coefficients, 183
- inequivalent spin structures, 239–242
- inflation, 48, 73–88
 - amplifies vacuum fluctuations by particle creation, 65

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)*Index*

451

- Einstein equations, 78
- history, 73
- inflaton field, 73
- new inflation, 74
- perturbations, 65, 71
- reheating, 75
- slow-roll parameters, 79
- inflaton field, 65, 71
 - dispersion and two-point function, 71
 - energy density and pressure, 78
 - inflation, 73
 - inflaton potential, 75
 - inhomogeneous quantized perturbations, 75
 - spectrum of perturbations, 71
- inflaton perturbations
 - asymptotic condition on modes, 81
 - field equation, 80
 - momentum-space components, 83
 - nearly scale-invariant, 75
 - quantization, 80
 - spectrum of, 82
- inflaton potential
 - conditions for slow-roll inflation, 79
- integration of Gaussian
 - Berezin case, 244
 - finite dimensional case, 189
 - infinite dimensional case, 189
- interacting fields
 - in curved spacetime, 90
 - local momentum-space representation, 90
 - operator product expansions in curved spacetime, 91
- interaction part of the action, 297
- interaction picture, 5
- invariants for electromagnetic field, 207
- involution, 246
- isometry, 39
 - and Killing vector, 41
- Jacobi identity, 354
- Jacobi relation, 351
- Jacobian
 - conformal transformation, 218–220
 - general gauge theory, 389
 - in polar coordinates, 412
- Kerr solution, 154
- Killing vector
 - and conserved generalized momentum, 41
 - and isometry, 41
- Killing's equation, 371
 - DeWitt metric, 375
 - Yang-Mills theory, 373
- Lagrangian
 - for Dirac equation in curved spacetime, 145, 247
- Landau gauge, 412
- Landau-DeWitt gauge
 - gravity, 368
 - importance, 384
 - Yang-Mills theory, 365, 401
- Legendre transformation, for effective action, 281, 290
- Levi-Civita tensor, 207, 334
- Lie algebra
 - non-Abelian gauge group, 351
- Lie bracket, 354
- Lie derivative
 - and infinitesimal coordinate transformation, 38
 - metric tensor, 108
- linked cluster theorem, 340, 342
- local Lorentz transformation
 - defined, 222
 - for fields, 224
 - infinitesimal form, 224
- local momentum space method, 134, 308
- local momentum-space representation
 - interacting fields, 90
- local orthonormal frame, 221
- local quantum field theory, 271
- loop expansion
 - effective action, 298–302
- Lorentz group Lie algebra, 225
- Lorentz invariance violation
 - and thermal spectrum, 180
 - and trans-Planckian physics, 180
- Lorentz transformation, 32
- Lorenz gauge, 348
- Majorana representation, 237
- Majorana spinor, 237
 - restrictions on spacetime dimension, 237
- Maxwell field, 26
- metric, 37
- metric of evaporating black hole, 179
- minimal coupling, 26, 37
- minimal operator, 367
- Minkowski space
 - accelerated detector, 125
- Minkowski spacetime, 1
 - initial, 49, 51
 - Rindler coordinates, 125
- models of black hole evaporation, 181
- Noether's theorem, 10
- non-Abelian Lie groups, 26

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

452

Index

- non-linear sigma model
 - invariance properties of classical theory, 334
 - not renormalizable in more than two spacetime dimensions, 335
 - renormalization, 336
- non-local divergences, 315
- non-perturbative effects
 - R -summed propagator, 93
- normal coordinate local momentum-space expansion, 94
- interacting fields, 94
- normal coordinate momentum space
 - adiabatic expansion of Green function, 139
 - derivation of configuration space
 - DeWitt-Schwinger or heat kernel series, 142
 - derivation of trace anomaly, 141
 - dimensional regularization in, 141
 - Green function boundary conditions by displacing poles, 140
 - Green function in, 138
- normal coordinates, *see* Riemann normal coordinates
- normal neighbourhood, 134
- null geodesics
 - affine parameter, 158
 - Carter constant and principal null congruence in Kerr, 159
 - from past to future null infinity in Kerr, 162
 - from past to future null infinity in Schwarzschild, 158
 - in Kerr, 159
 - in Schwarzschild, 156
 - in Schwarzschild and Kerr, 154
 - principal null congruence in Kerr, 159
- one-loop effective action
 - as determinant of differential operator, 188
 - as functional integral, 188–190
 - comparison of cut-off method and dimensional regularization, 196
 - comparison of dimensional and ζ -function regularization, 199
 - Dirac spinor, 248
 - divergent part, 194
 - divergent part, spinors, 249
 - divergent part, Yang-Mills theory, 405
 - functional integral in Riemannian space, 197
 - general definition, 299
 - in terms of heat kernel, 193
 - in terms of in-out transition amplitude, 185
 - pole part, scalar electrodynamics, 417
 - scalar electrodynamics, 413, 416
- one-loop effective Lagrangian
 - constant electric field, 209–210
 - constant electric field, imaginary part, 209, 256
 - constant electromagnetic field, 205–210
 - constant electromagnetic field, spinors, 255
- one-loop effective potential
 - scalar electrodynamics, 419
 - scalar electrodynamics, massless limit, 419
- one-particle irreducible, 301
- open algebra, 354
- orbit space, 359
- Page approximation, 94, 118
 - and Fulling, Davies, Unruh effect, 125
 - and Gaussian approximation, 117
 - and Hadamard regularization, 121
- de Sitter and Schwarzschild metrics, 127
- derivation, 122
- derivation of temperature observed by
 - accelerated observer in Minkowski spacetime, 125
- energy-momentum tensor and field
 - fluctuations exact for de Sitter invariant thermal state, 128
- energy-momentum tensor and field
 - fluctuations in thermal state of Schwarzschild black hole, 128
- exact in Minkowski spacetime, 125
- Hadamard regularization, 124
- relation to Gaussian approximation, 123
- ultrastatic metric, optical metric, 122
- parallel propagation, 332
- parallelizable
 - defined, 239
 - global definition of spinors, 239
- partially summed form of amplitude or heat kernel, *see* R -summed form
- particle creation
 - black body radiation, 64
 - coherent superposition of pairs, 64
 - exact solution, 61, 63
 - from imaginary part of effective action, 133
 - gravitons, 58
 - in anisotropically changing universes, 58
 - none for conformally-invariant free fields in Robertson-Walker universes, 57
 - none for free massless neutrinos and photons in Robertson-Walker universes, 58
 - of conformal scalar field with quartic self-interaction, 110

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

Index

453

- probability distribution, 60
- stimulated creation of bosons, 60
- particle creation by black holes
 - Hawking flux pressure, energy density and current, 177
 - Hawking thermal radiation, 153
 - history, 152
 - probability distribution, 153
 - wave packets, 169
- particle creation by Schwarzschild and Kerr
 - black holes, 165–172
- particle number
 - early times, 53
 - expectation value, 52
 - measurement, 53
- particle number operator, 16, 25
- particle properties, 17
- path integral, *see* Feynman path integral
- Pauli matrices, 234
- Penrose conformal diagram, 157
- periodic δ -function, 213
- periodic boundary conditions, 211
- periodically identified spacetime, 210
- physical quantities quadratic in fields
 - energy-momentum tensor, 93
- point splitting regularization
 - using time-ordered product, 141
- point-splitting
 - coincidence limit, 120
 - Hadamard regularization, 120
- Poisson bracket relations for classical
 - mechanics, 268
- positive frequency
 - ambiguity, 53
 - early times, 51
 - late times, 52
- principle of stationary action, for operators, 275
- probability distribution
 - of created particles, 60
- projection operator P^i_j , 359
- propagator, *see* Green function
 - R -summed form, 130
- proper time, 52, 200
- proper time series
 - from normal coordinate momentum space expansion of Green function, 142
- quantized field in black hole spacetimes, 162–165
- quantized inflaton field
 - discrete and continuous representations, 423
- quantized inflaton perturbations
 - and ensemble average over random phases, 423
 - and regularization, 84
 - power spectrum in discrete and continuous representations, 423
 - properties in discrete and continuous representations, 422
- reduction of gauge theory to non-gauge theory, 410
- regularization, 18
 - ζ -function, 196–199
 - cut-off, 195
 - dimensional, 195–196
 - dimensional, zeta-function, point-splitting, Hadamard, adiabatic, 93
- renormalization, 18
 - $\lambda\phi^4$ in curved spacetime, 90
 - interacting field in curved spacetime, 302–317
 - non-Abelian gauge theories in curved spacetime, 90
 - of interacting fields in curved spacetime, 90
 - quantum electrodynamics in curved spacetime, 90
 - scalar field in constant electromagnetic field, 208–209
 - Yang-Mills theory in curved spacetime, 399–407
- renormalization conditions, 324
- renormalization counterterms, 318
- renormalization factors, related in Yang-Mills theory, 406
- renormalization group
 - in curved spacetime, 91
 - related to rescaling of background metric, 320
- renormalization group equation
 - effective action, $O(N)$ model, 325
 - effective potential, $O(N)$ model, 326
 - effective potential, curved spacetime, 328
 - for coupling constants, 321
 - for effective action, 321
 - Yang-Mills theory, 407
- renormalization length, 188, 303, 319
 - dimensional regularization, 206
- renormalization of scalar field
 - one-loop order, 305
 - two-loop order, 306–317
- renormalized gauge field, 209
- Ricci scalar, *see* scalar curvature
- Riemann curvature
 - from curvature two-form, 224

Cambridge University Press

978-0-521-87787-9 - Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity

Leonard E. Parker and David J. Toms

Index

[More information](#)

454

Index

- Riemann normal coordinates, 134
 - coordinate transformation, 137
 - geodesics, 134
 - Green function in, 137
 - metric, 135, 136
- scalar curvature, 43
- scalar electrodynamics
 - curved spacetime, 407–417
 - effective potential, 417–419
- scalar field, 13, 24, 43
 - arbitrary mass and coupling
 - constant, 54
 - de Sitter spacetime, 67
- scalar product, 14, 28, 30, 46
- Schrödinger picture, 3
- Schrödinger representation, 3, 7, 19
- Schwarzschild solution, 153
- Schwinger action principle, 1, 10
 - for general fields, 271–276
 - for in-out transition amplitude, 185
 - in curved spacetime, 39
 - variation of external source, 277
- Schwinger effective Lagrangian
 - scalars, 209
 - spinors, 256
- Schwinger-Keldysh closed-time-path formalism
 - in curved spacetime, 183
- second law of thermodynamics
 - Kerr black hole, 173
- sonic black hole
 - and thermal spectrum, 180
- spectrum of quantized inflaton perturbations
 - nearly scale-invariant, 77
- spin, 29, 33
- spin connection, 144
 - definition, 225
 - transformation, 225
- spin-statistics, 30, 36, 47
 - Bose-Einstein statistics from dynamics, 55
 - Fermi-Dirac statistics from dynamics, 55
 - from dynamics in curved spacetime, 54
 - generalized statistics, 55
 - ghost fields, 55
 - higher spin fields, 55
- spinorial affine connections
 - and vierbein, 145
- Steiffel-Whitney class, 239
- string theory black hole
 - Hawking radiation and gray-body factor, 181
- structure constants, 27
 - Lie algebra, 351
- structure functions
 - definition, 354
 - gravity, 359
 - Yang-Mills theory, 357
- super-radiant scattering
 - by Kerr black hole, 172
- surface gravity
 - Kerr black hole, 161, 171
 - Schwarzschild black hole, 161
- surface of last scattering, 65
 - recombination, 75
- thermal state
 - Green function, 121
- time reversal, 53
 - correlations, 53
- time-ordered product, 278
- topologically massive gauge theory, 267
- trace anomaly, 106, 142
 - conformally-coupled scalar field, 106
 - derived in normal coordinate momentum space, 141
 - energy-momentum tensor, 93
 - energy-momentum tensor from, 108, 110
 - for higher spin, 107
 - for spin-0, 114
 - for spin-1/2 and spin-1, 114
 - functional integral derivation, 220
 - manifestly covariant expression, 107, 113
 - manifestly covariant expression in general curved spacetime, 107
 - same in any state satisfying adiabatic condition, 141
 - spinor field, 253
- trace of an operator, 188
- trans-Planckian physics
 - and CMB fluctuation spectrum, 181
- transformation function, 272
- transition amplitude, 272
 - expressed as functional integral, 287–289
- ultrastatic metric, 122
- unitary gauge, 411
- units, 2
- vacuum diagrams, 301
- vacuum energy, 18, 21, 24
- vacuum state, 1, 16, 19
 - adiabatic vacuum state, 96
 - ambiguity, 1, 47, 53
 - Bunch-Davies vacuum, 82
 - Bunch-Davies vacuum, 71
 - conformal, 53
 - conformal invariance, 47
 - Hartle-Hawking thermal equilibrium state, 174

late times, 58	volume element
of eternal black hole with Hawking flux; Unruh vacuum, 175	gauge theories, 385
Poincaré invariance, 1	wedge product, 223
unique for conformally coupled massless scalar, Dirac, and two-component neutrino fields, 53	Wess-Zumino term, 334
unique for conformally-invariant free fields in Robertson-Walker universes, 57	Weyl representation, 234
with no incoming particles from past null infinity, 175	Weyl spinor
with no particles incoming from past null infinity in gravitational collapse, 164	left-handed, 236
Van Vleck-Morette determinant, 111, 288	not possible in odd spacetime dimensions, 236
vector current, 263	right-handed, 235
of Dirac field in curved spacetime, 145	Weyl tensor squared, 113
vector potential, 348	Weyl-Majorana spinor, 238
vierbein field, 145	restriction on spacetime dimension, 238
	Wick's theorem, 298
	Yang-Mills field, 27
	Yang-Mills theory, 349