CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Index

ADM (Arnowitt–Deser–Misner) formalism, *see also* 3+1 split
  assembled, 81
  numerical implementations, 86, 106–107
  reformulations, 111–117
  summarized, 199
Ampère's law, 46
Apparent horizons, *see* Horizons
Areal radius, *see* Circumferential radius
Asymptotic flatness, 27–29, 92–100

Baker, John, 127
Barish, Barry, x, 34
Bases, *see* Vectors; One-forms; Tensors
Bianchi identity, *see also* Constraint equations; Gauge freedom
  and equations of motion, 136, 190, 192
  electromagnetic, 50–52, 71
  general relativistic, 21, 71
    contracted, 71
  summarized, 196
Binaries
  black hole, *see also* Gravitational waves
    detections, 34, 42, 124–126, 136, *see also* Gravitational wave interferometers
    initial data, 103–104, 128, 131, *see also* Bowen–York initial data; Puncture initial data
    numerical evolution, 126–134
    orbital hang-up, 132
    recoil, 132
    spin flip, 133
  neutron star, *see also* Gravitational waves; Gamma-ray bursts; Kilonovae; Pulsars
    detections, 35, 38, 39, 41–42, 125, 136, *see also* Gravitational wave interferometers
    initial data, 104
    numerical evolution, 124, 137
    pulsar, 34
  Newtonian point-mass, 35–41
    gravitational wave amplitude, 36
    gravitational wave frequency, 37, 38
    orbital angular velocity, *see* Kepler's law
    orbital decay time, 40
  post-Newtonian, 42, 134–136
Birkhoff's theorem, 29, *see also* Schwarzschild spacetime
Black holes
  binaries, *see* Binaries
  excision, 128
  horizons, *see* Horizons
  initial data, *see* Brill–Lindquist initial data; Bowen–York initial data; Puncture initial data; Schwarzschild spacetime
  introduced, ix, 26–33
  nonrotating, *see* Schwarzschild spacetime
  precession, 134
  recoil, *see* Binaries
  rotating, *see* Kerr spacetime
Boundary conditions, *see also* Asymptotic flatness; Numerical techniques
  and constraint violations, 110
  Dirichlet, 155
  Neumann, 155
  outgoing-wave, 155, 171–172
  periodic, 109
  Robin, 155–156, 158, 160

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Boundary-value problems, *see also* Numerical techniques; Grids; Initial data; Boundary conditions
  introduced, 155
  linear, 155–158
  matrix inversion, 157–158
    band-diagonal matrix, 158
    tridiagonal matrix, 157
  nonlinear, 158–159
    iteration, 158–159
    linearization, 158–159
  Poisson-type equation, 91, 94, 160
  residual, 159
  super-index, 157
  worked numerical example, 160–168
Bowen–York initial data, *see also* Puncture initial data
  boosted, 100, 103
  in puncture initial data, 101–104
  introduced, 97–101
  spinning, 100, 103
    compared with Kerr spacetimes, 104–105
  worked numerical example, 160
Brill–Lindquist initial data, 93
BSSN (Baumgarte–Shapiro–Shibata–Nakamura) formalism
  in black-hole simulations, 128
  introduced, 111–115
  summarized, 116

Campanelli, Manuela, 126
Cauchy problem, *see* Initial-value problems
Centrella, Joan, 127
Chirp mass, *see* Mass
Choptuik, Matthew, 124
Christoffel symbols
  analogy with Newtonian gravitational fields, 20
  in derivation of covariant derivative, 147
  in local Lorentz frame, 22
  introduced, 18–20
  spatial, *see also* Minkowski spacetime
    conformal decomposition, 90
    flat space in spherical polar coordinates, 149
    introduced, 76–77
  summarized, 195
Circumferential radius, 26, 28, 129, *see also* Schwarzschild spacetime
Codazzi equation, 78, 79, 198
Codazzi–Mainardi relation, *see* Codazzi equation
Color coding
  introduced, 45
  summarized, 83
Commutator, 65, 147, *see also* Lie derivative
Conformal connection functions, 114–115, 122
Conformal decompositions, *see also* Christoffel symbols; Conformal factor; Conformal flatness; Extrinsic curvature; Hamiltonian constraint; Metric; Momentum constraint, Ricci tensor; Ricci scalar
  in evolution equations, 113–114
  introduced, 89–91
  summarized, 199
  thin-sandwich, 97, 104–105, 131
  transverse-traceless, 94–97
Conformal factor, *see also* Conformal decompositions
  exponent, 113
  introduced, 90
Conformal flatness, *see also* Conformal decompositions; Initial data
  Bowen–York initial data, 97–101, 104–105
  Brill–Lindquist initial data, 93
  introduced, 92
  Schwarzschild spacetime, 93
Conformal imaging, 101
Connection coefficients, 147, *see also* Christoffel symbols
Constraint equations, *see also* Initial data
  as examples of boundary-value problem, 155
  electromagnetic fields, 47–48
    follows from electromagnetic Bianchi identity, 52, 71
    from normal projection of field equations, 68
    preserved by evolution equations, 47, 108
  gravitational fields, *see also* Hamiltonian constraint; Momentum constraint
    follow from Bianchi identity, 71
    from normal projection of field equations, 79–80
    preserved by evolution equations, 81
    summarized, 199
  scalar fields, 45
  violations, 108–111, 115, 186–188, *see also* evolution equations
Continuity equation, 48, 51

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Convergence, *see also* Numerical techniques
  order, 153
  tests, 187–189
Cosmological constant, 25, *see also* Dark energy; Einstein's field equations
Courant factor, 171, 186, *see also* Initial-value problems
Covariant derivative, *see also* Christoffel symbols; Parallel transport
  compatible with metric, 75, 148
  contrasted with Lie derivative, 65
  derived, 146–150
  deviation from parallel transport, 19, 148
  illustrated, 19
  introduced, 16–20
  properties, 150
  spatial, 63, 76–77
  summarized, 195–196
Critical phenomena, 124, 194
Current
  spacetime
    decomposed, 60
    introduced, 50
  spatial, 46
Curvature, *see also* Extrinsic curvature; Metric tensor; Riemann tensor; Singularity
  as origin of gravitation, 9
  how to measure, 9, 15–16, 22–23, *see also* Riemann tensor; Parallel transport; Geodesic deviation
    illustrated, 10, 22
  how to visualize, *see* Embedding diagram
  in Einstein's field equations, 24
  of Newtonian trajectory, 1

Dark energy, 25, *see also* Cosmological constant
Degrees of freedom, 83
Dual-frame formalism, 76

Einstein, Albert, 9, 16, 25, 26, 34
Einstein tensor
  introduced, 24
  summarized, 197
Einstein Toolkit, 103, 115, 139
Einstein's field equations
  analogy with Maxwell's equations, 81–86
  analogy with Poisson equation, 23, 25
  analogy with scalar field equation, 82–86
  decomposed, *see* 3+1 split
  introduced, 23–25
  linearized, 33
  solutions, *see* Gravitational waves; Kerr spacetime; Schwarzschild spacetime
  summarized, 197
Einstein's gravity, *see also* Einstein's field equations; Metric
  first acquaintance, 8–26
Electric field
  four-vector, 49
  three-vector, 46
Electrodynamics, *see* Maxwell's equations
Embedding diagram, *see also* Schwarzschild spacetime
  trumpet, 31–32
  wormhole, 27–29
EOB (Effective-One-Body) formalism, 135
Event horizons, *see* Horizons
Evolution equations, *see also* Initial-value problems; Numerical techniques; Boundary conditions
  as example of initial-value problem, 155
  comparison for different fields, 82–86
  electromagnetic fields, 47, 73, *see also* Maxwell's equations
    from spatial projection of field equations, 68
    reformulated, 107–111, *see also* Constraint violations
  gravitational fields, 80–81
    from spatial projection of field equations, 80–81
    reformulated, 111–117, *see also* ADM formalism; BSSN formalism; Constraint violations; General harmonic; Z4
    summarized, 199
  scalar fields, 45, 69
Extrinsic curvature, *see also* Minkowski spacetime; Schwarzschild spacetime
  analogy with electric field, 75–76
  conformal decomposition
    evolution, 114
    initial data, 95–97
  evolution equation, 80
  illustrated, 61
  introduced, 61
  Lie derivative of spatial metric, 74–75
  mean curvature, 66, *see also* Maximal slicing
    evolution equation, 81
  summarized, 198

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Faraday tensor, 48–54, *see also* Maxwell's equations
  decomposition, 62–66
  for arbitrary observer, 49
  in local Lorentz frame, 49
  in terms of vector potential, 51
  transformation, 145
Faraday's law, 46
Fermat's principle, 16
Flat spacetime, *see* Minkowski spacetime
Foliations of spacetime, *see* 3+1 split

Galilei, Galileo, 3
Gamma-driver condition, 122, 128, *see also* Moving-puncture gauge; Spatial coordinates
Gamma-ray bursts
  GRB 170817A, 136
Gauge freedom, *see also* Lapse; Shift
  comparison, 85
  electromagnetic fields, 47, 69, 83
    follows from electromagnetic Bianchi identity, 52, 71
  gravitational fields, 83
    follows from Bianchi identity, 71
  scalar fields, 83, 85
  versus coordinate freedom, 76
Gauge source functions, 117, *see also* Generalized harmonic formalism; Harmonic coordinates
Gauss, Carl Friedrich, 10
Gauss equation, 78, 79, 198
Gauss's law, 46
Gaussian normal coordinates, *see* Geodesic slicing
General harmonic formalism, 115–117, 128
General relativity, *see* Einstein's gravity
Geodesic deviation, *see also* Riemann tensor
  analogy with Newtonian tidal deviation, 21
  introduced, 20–23
  summarized, 197
Geodesic slicing, 117–118, 120, *see also* Slicing; Spatial coordinates
Geodesics, *see also* Christoffel symbols; Parallel transport
  analogy with Newtonian equation of motion, 20
  geodesic equation, 17
  introduced, 16–17
Gravitational wave interferometers
  detections
    catalog, 126
    GW150914, 34, 42, 124–125, 136, 139
    GW170817, 35, 39, 42, 136–137, 139
  LIGO, x, 34, 39, 41, 124–125
  LISA, 42
  Virgo, 39, 41
Gravitational waves
  binary waveforms, 39–41, *see also* Weyl scalar
    inspiral, 40, 125
    ringdown, 125–126
  catalogs, *see also* NINJA; NRAR, 134
    EOBNR, 136
    IMRPhenom, 136
    RIT, 134
  detections, *see* Gravitational wave interferometers
  electromagnetic counterparts, *see* Gamma-ray bursts; Kilonovae
  introduced, 33–42
  linear wave equation, 33
  perturbation methods, 40
  ringdown, 40
  weak-field, slow-velocity
    binary inspiral rate, 40
    binary wave amplitude, 36
    binary wave frequency, 37
    quadrupole emission formula, 36
    quadrupole wave solution, 35
Gravity
  important gravitational quantities, 8
  nonrelativistic, *see* Newton's gravity
  relativistic, *see* Einstein's gravity
Grid, *see also* Numerical techniques
  cell-centered, 154
  cells, 154
  introduced, 151
  numerical worked examples, 161–168, 175–187
  points, 103, 110, 119, 128, 154
  resolution, 151, 168, 186–189
  spacing, *see* resolution
  staggered, 154
  uniform, 151
  vertex-centered, 154

Hahn, Susan, 123
Hamiltonian constraint
  conformal decomposition, 89–94
  introduced, 79

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

solutions, *see* Brill–Lindquist solution; Puncture initial data; Schwarzschild spacetime
summarized, 199
Harmonic coordinates, 112, 117, 119, *see also* Slicing, Spatial coordinates
Harmonic slicing, 119–120, *see also* Slicing
Hilbert action, 25, *see also* Lagrangian density
Horizons
and black-hole excision, 128
and trumpet geometries, 129, 130
apparent horizons, 30, 105
event horizons, 30, 105
introduced, 30–31
merging, 126, 127
Schwarzschild spacetimes, 28, 31, 32
trapped surfaces, 30
Hubble, Edwin, 25
Hulse, Russell, 34
Hulse–Taylor pulsar, *see* Pulsars
Hydrodynamics, 137, 139, 190
Hypersurface, *see* Time slice

Illustris simulation, 133
Inflation, 194
Inflaton, *see* Inflation
Initial data, *see also* Boundary-value problems; Constraint equations; Numerical techniques
comparison, 84–85
electromagnetic fields, 47, 69
worked numerical example, 172
gravitational fields, 81, *see also* Hamiltonian constraint; Momentum constraint
black holes, *see* Brill–Lindquist initial data; Bowen–York initial data; Puncture initial data; Schwarzschild spacetime
freely specifiable versus constrained variables, 87–89
worked numerical example, 160–168
scalar fields, 45
Initial-value problems, *see also* Numerical techniques; Grid; Boundary conditions
Courant–Friedrich–Lewy condition, 171, *see also* Courant factor
Euler method, 170
FTCS (forward-time-centered space), 170
introduced, 155
iterative Crank–Nicholson, 170
method of lines, 169–172
Runge–Kutta, 170
symmetric hyperbolicity, 44
von Neumann stability analysis, 170
well-posedness, 44
worked numerical example, 172–187

Jets, 133
Junk radiation, 131

Kepler's law, 36–41, 93
Kerr spacetime, 30, 33
compared with Bowen–York solution, 104, 105
maximal spin, 132
remnant of merger, 132
Kilonovae
AT 2017gfo, 136
Klein–Gordon equation, *see* scalar fields

L2-norm, 110, 174, 186
Lagrangian density
geometric, 25
matter, 25
electromagnetic fields, 191
scalar fields, 193
Lapse, *see also* Metric tensor; Minkowski spacetime; Schwarzschild spacetime
acceleration of normal observer, 64
choices, *see* Slicing
collapse of the lapse, 119
illustrated, 57
in binary black hole simulation, 127
introduced, 56
pre-collapsed, 122
Levi–Civita tensor
spacetime, 49
spatial, 64
Lie derivative
contrasted with covariant derivative, 65
introduced, 64–65
of spatial metric, 74–75
of spatial tensor, 65
summarized, 196
LIGO, *see* Gravitational wave interferometers
Lindquist, Richard, 123
Line element, *see* Metric tensor
LISA, *see* Gravitational wave interferometers
Local Lorentz frame, 22, *see also* Metric tensor
Lousto, Carlos, 126

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Magnetic field
  four-vector, 49
  three-vector, 46
Magnetohydrodynamics (GRMHD), 115, 137, 139
Mass
  chirp, 37–42
  gravitational, 92, 105
  in Newton's gravity, 1
    gravitational versus intertial, 2–3, 8–9
    reduced, 36
  in Schwarzschild spacetime, 26
  puncture, 102, 105
    versus gravitational, 105
Mass–energy density
  defined, 79
  electromagnetic, 193
  scalar fields, 194
Mass–energy flux
  defined, 79
  electromagnetic, 193
  scalar fields, 194
Maximal slicing, *see also* Slicing
  as example of boundary-value problem, 155
  defined, 98, 118
  in constraint equations, 98–100
  in evolution calculations, 118–119
  limit of lapse evolution, 120–121
  singularity avoidance, 118
Maxwell's equations
  analogy with Poisson equation, 51
  derived from stress–energy tensor, 191–192
  for general 3+1 splittings, 68
  standard form, 46
  with Faraday tensor, 50
  with spacetime vector potential, 51
  with spatial vector potential, 47
    reformulated, 107–111
  worked numerical example, 172–187
May, Michael, 123
Mean curvature, *see* Extrinsic curvature
Metric tensor, *see also* Minkowski spacetime; Schwarzschild spacetime; Roberston–Walker spacetime
  3+1 decomposition, 71, 72
    inverse, 72
    summarized, 198
  analogy with Newtonian potential, 10
  defined, 141
  determinant, 74
    and tensor density, 115
  in local Lorentz frame, 22
  introduced, 9–16
  reference, 114, 115
  spacetime interval, 12–13
    null, 13
    space-like, 12
    time-like, 12
  spacetime Pythagorean theorem, 73
    illustrated, 73
  spatial
    analogy with vector potential, 72, 76
    conformal decomposition for evolution, 113
    conformal decomposition for initial data, 89
    determinant, 80, 112–114
    introduced, 72
    summarized, 198
Minkowski spacetime, 11
  Cartesian coordinates, 11
  height function coordinates
    extrinsic curvature, 61–62, 80
    Hamiltonian constraint, 80
    illustrated, 56
    introduced, 55–56
    lapse, 56, 74
    normal vector, 55–56
    projection operator, 59
    sequence of exercises, 55
    shift, 58, 74
    spatial Christoffel symbols, 77
    spatial metric, 74
    spatial Ricci scalar, 80
    spatial Ricci tensor, 77–78
  perturbation, 33
    trace-reversed, 33
  spherical polar coordinates, 13
Momentum constraint
  conformal decomposition, 94–97
  introduced, 79
  solutions, *see* Bowen–York initial data
  summarized, 199
Momentum density, *see* Mass–energy flux
Moving-puncture gauge, *see also* 1+ log slicing; Gamma-driver condition; Trumpet geometry
  as example of initial-value problem, 155
  in binary black hole simulations, 128–130
  introduced, 122
Multimessenger astronomy, x, 35, *see also* Gamma-ray bursts; Jets; Kilonovae

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Neutron stars, ix, *see also* Binaries; Gravitational waves; Gravitational wave interferometers; Pulsars
Newton's gravity
  acceleration, 2
  brief review, 1–8
  equation of motion, 3
  field equation, 6, *see also* Poisson equation
  mass in, *see* Mass
  potential, 2, 6
  tidal effects
    tidal deviation, 5
    tidal force, 4
    tidal tensor, 6–7
Newton, Sir Isaac, 1–3, 9
Newtonian potential, *see* Newton's gravity
NINJA (Numerical INJection Analysis) collaboration, 134
Normal vector
  covariant derivative, 60, 62, *see also* Extrinsic curvature
  illustrated, 56
  in projection operator, 59
  in terms of lapse and shift, 57
  introduced, 54
  observer, 55
    acceleration, 62, 64
  summarized, 197
NRAR (Numerical-Relativity–Analytical-Relativity) collaboration, 135
Numerical examples
  codes
    electromagnetic wave evolution, 175–186
    puncture initial data, 161–168
  exercises
    electromagnetic wave evolution, 110–111, 186–187
    puncture initial data, 103–104, 168
Numerical techniques, *see also* Boundary-value problems; Initial-value problems
  discontinuous Galerkin methods, 151
  finite-difference, 151–154, *see also* Grid convergence, *see* Convergence
  derivatives, 152–154
  matrix inversion, *see* Boundary-value problems
  residual, *see* Boundary-value problems
  spectral, 151
    convergence, 151
  stability, *see* Initial-value problems

One-forms, *see also* Vectors; Tensors
  basis one-forms, 14, 141
  components, 141
  gradient, 14, 145
  introduced, 141–146
  spatial slice, 57
  transformation, 143–145
1+ log slicing, *see also* Moving-puncture gauge; Slicing
  and trumpet geometry, 128–129
  in moving-puncture gauge, 122, 128
  introduced, 120–121
Orbital hang-up, *see* Binaries

Parallel transport
  around closed loop, 22–23, *see also* Riemann tensor
    illustrated, 22
  geodesic, 19
  illustrated, 19
  introduced, 18–19
Poisson equation, *see also* Einstein's field equations; Maxwell's equations; Newton's gravity; Scalar fields
  as example of boundary-value problem, 155
  introduced, 6
Polarization, 83, 86
Post-Newtonian approximation, *see* Binaries
Poynting vector, 192, 193, *see also* Mass–energy flux
Pretorius, Frans, 115, 126–131
Projection operator, 59
Proper distance, 12
Proper time, 12
Pulsars
  PSR 1913+16 (Hulse–Taylor pulsar), 34
Puncture initial data
  binary black holes, 103, 131
  introduced, 101–103
  worked numerical example, 160–168

Quadrupole emission formula, 36, *see also* Gravitational waves

Recoil, *see* Binaries
Ricci equation, 78, 79, 198

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

Ricci scalar
  introduced, 23
  spatial, 80, 89, *see also* Minkowski spacetime
    conformal decomposition, 90–92
  summarized, 197
Ricci tensor
  introduced, 23
  spatial, 77–80, *see also* Minkowski spacetime
    conformal decomposition, 90–91
  summarized, 197
Riemann tensor
  analogy with Newtonian tidal tensor, 21
  in geodesic deviation, 21
  in parallel transport, 22–23
  introduced, 21
  spatial, 77
    conformal decomposition, 90–91
  summarized, 196
Robertson–Walker metric, 118

Scalar fields
  analogy with Poisson equation, 44
  field equation
    derived from stress–energy tensor, 193
    first-order form, 44
    for general 3+1 splittings, 69
    standard form, 43
  inflaton, *see* Inflation
  introduced, 43–44
  Klein–Gordon equation, 43, 193
  mass, 43, 193
  potential, 193
Schwarzschild spacetime
  Hamiltonian constraint, 92–93
  introduced, 26–27
  isotropic coordinates
    Hamiltonian constraint, 92
    horizon, 31
    introduced, 29
    lapse, shift, and spatial metric, 74
  Painlevé–Gullstrand coordinates, 32
  raindrop coordinates, *see* Painlevé–Gullstrand coordinates
  Schwarzschild coordinates, 26
    embedding diagram, 27–29
  singularities, *see also* Singularity
    coordinate, 27, 31
    spacetime, 27
  trumpet coordinates
    1+ log slicing, 121–122
    embedding diagram, 31–32
    extrinsic curvature, 81
    Hamiltonian constraint, 93
    horizon, 30–31
    introduced, 29–30
    lapse, shift, and spatial metric, 74
    properties, 129
    sequence of exercises, 32
Schwarzschild, Karl, 26
Shibata, Masaru, 124
Shift, *see also* Metric tensor; Minkowski spacetime; Schwarzschild spacetime
  choices, *see* Spatial coordinates
  illustrated, 57
  introduced, 58
Singularity, *see also* Schwarzschild spacetime
  avoidance, *see* Slicing
  coordinate, 27, 31, 118, 130
  in constraint equations, 101
  in evolution calculations, 128
  spacetime, 27, 129–130
Slicing, *see also* 3+1 split; Embedding diagram; Lapse
  choices, *see* 1+ log slicing; Maximal slicing; Geodesic slicing; Harmonic slicing
  collapse of the lapse, *see* Lapse
  concept, 54–55
  grid stretching, 119
  singularity avoidance, 118–121, *see also* 1+ log slicing; Maximal slicing
Smarr, Larry, 123
Spacetime diagrams, 12–13
  event, 17
  light cones, 13
    future, 13
    past, 13
  orthogonal vectors, 15
  world line, 17
Spatial coordinates
  choices, *see* Gamma-driver condition; Geodesic slicing; Harmonic coordinates, Moving-puncture gauge
SpEC code, 117
Spin flips, *see* Binaries
Stress–energy tensor
  decomposition, 79–80, 192–194, *see also* Mass–energy density; Mass–energy flux

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-84411-6 — Numerical Relativity: Starting from Scratch
Thomas W. Baumgarte , Stuart L. Shapiro
Index
More Information

electromagnetic fields
in terms of electric and magnetic fields, 192
in terms of Faraday tensor, 191
source terms, 192
introduced, 24
scalar fields, 193
vacuum, 24

Taylor, Joseph, 34
Tensors, *see also* Einstein tensor; Faraday tensor; Levi–Civita tensor; Metric tensor; One-forms; Projection operator; Riemann tensor; Ricci tensor; Stress–energy tensor; Vectors
abstract tensor notation, 15
basis tensors, 140–146
coordinate, or holonomic, 143
orthonormal, 143
brief review, 140–150
components, 140–141
contraction, 141
covariant versus contravariant indices, 13–14, 140–142
density, 115
derivative, *see* Covariant derivative
outer product, 142
rank, 6, 140
spatial versus spacetime, 59
symmetries, 142
tidal, *see* Newton's gravity
transformations, 143–146
coordinate, 145
Lorentz, 144
Teukolsky, Saul, 124
Thorne, Kip, x, 34
3+1 split
comparisons, 82–86
electrodynamics, 58–70
gravitational fields, 70–81
scalar fields, 46
spacetime kinematics, 54–58
summarized, 197–198
Tidal effects, *see also* Newton's gravity; Riemann tensor
Newtonian versus relativistic, 21–22
Time slice, *see also* 3+1 split; Slicing
illustrated, 56
introduced, 54–55
Time vector, 58, 66, 73
Trapped surfaces, *see* Horizons
Trumpet geometries, *see* Embedding diagram; Schwarzschild spacetime
Twin paradox, 16

Units
geometrized, 11, 160
natural, 43, 193
physical, 37
reinserting constants, 37–38
Unruh, William, 128

Vacuum spacetimes, 24, *see also* Black holes; Gravitational waves; Minkowski spacetime
Vector gradient, 96
Vector Laplacian, 96, 98
Vector potential, *see also* Maxwell's equations
spacetime
decomposed, 58
introduced, 51
spatial, 46
Vectors, *see also* Current; Normal vector; One-forms; Tensors; Vector potential
acceleration, 62
basis vectors, 14, 18, 140
components, 140–141
displacement vector, 14, 145
dot product, 14, 140
four-velocity, 17, *see also* Normal vector
introduced, 140–141
transformation, 143–145
Virgo, *see* Gravitational wave interferometers

Weiss, Rainer, x, 34
Weyl curvature scalar, 130
Weyl tensor, 51
Wheeler, John, 25
White, Richard, 123
Wormhole geometries, *see* Embedding diagram

Z4 formalism, 115

© in this web service Cambridge University Press www.cambridge.org