

Index

- action principle, 75; n-body, in modified EIH formalism, 273; n-body, in PPN formalism, 158–60; n-body, in $\text{THE}\mu$ formalism, 54
 active gravitational mass: comparison with passive mass via Kreuzer experiment, 214; in PPN formalism, 151
 advanced time, 228
 anomalous mass tensors, 40
Apollo 11 retroreflectors, 188

 Bianchi identities, 76, 128, 230
 big-bang model, 311
 binary pulsar, 11, 257, 283; acceleration of center of mass, 300, 344; arrival-time analysis, 287–92, 343; in Brans–Dicke theory, 306, 349–50; companion, 284; decay of orbit, 297; detection of gravitational radiation, 306; determination of masses, 297, 344; dipole gravitational radiation, 298; formation and evolution, 286; in general relativity, 303–6, 344–6; gravitational radiation emission, 297; gravitational red shift, 290; mass loss, 300; measured parameters, 285, 345; periastron shift, 284, 293; post-Newtonian effects, 297; precession of pulsar spin, 302; pulsar mass in general relativity, 306; in Rosen's theory, 307; second-order Doppler shift, 290, 296; spin-down rate, 292; test of conservation of momentum, 218–20, 338; third body, 301; tidal effects in, 294, 299; as ultimate test for gravitation theory, 309

 binary system: single-line spectroscopic, 287; test of conservation of momentum, 217–20, 338
 black holes, 256; in general relativity, 264; motion, *see* modified EIH formalism; motion in Brans–Dicke theory, 279; in Rosen's theory, 266; in scalar-tensor theories, 265
 boundary conditions for post-Newtonian limit, 118
 Brans–Dicke theory, 125, 182, 190, 203, 265, 276, 306, 317, 332, 335, 349; *see also* scalar-tensor theories

 Cavendish experiment, 82, 153, 191
 center of mass, 113, 145, 146, 160
 Christoffel symbols, 70; for PPN metric, 144
 classical tests, 166; and redshift experiment, 166
 ‘‘comma goes to semicolon’’ rule, 71
 completeness of gravitation theory, 18
 connection coefficient, *see* Christoffel symbols
 conservation laws: angular momentum, 108; baryon number, 105; breakdown of, for total momentum, 149; center-of-mass motion, 108; and constraints on PPN parameters, 111; energy-momentum, 108, 111–12; global, 107–8; local, 105–7; rest mass, 106; tests of, for total momentum, 215–20, 337–8
 conserved density, 107, 111
 constants of nature, constancy: gravitational, 202; nongravitational, 36–8; and Oklo natural reactor 36–8
 coordinate systems: curvature coordi-

- nates, 259; local quasi-Cartesian, 92; preferred, 17; standard PPN gauge, 97
- coordinate transformation, 69
- Copernican principle, 312
- cosmic time function, 80
- cosmological principle, 312
- cosmology, 7, 310; in Bekenstein's variable-mass theory, 317; in Brans–Dicke theory, 317; in general relativity, 313; helium abundance, 315; microwave background, 311, 314; in Rastall's theory, 318; in Rosen's theory, 318; timescale problem, 311
- covariant derivative, 70
- Cygnus X1, 256
- de Sitter effect, 338
- deceleration parameter, 313
- deflection of light, 5; derivation in PPN formalism, 167–70; derivation using equivalence principle, 170; eclipse expedition, 5, 171; effect of solar corona, 172; measurement by radio interferometry, 172; optical measurements, 6; radio measurements, 172; VLBI, 332
- Dicke, R. H., 10, 16
- Dicke framework, 10, 16–18
- Doppler shift in binary pulsar, 290, 293, 296
- dynamical gravitational fields, 118
- E(2) classification, *see* gravitational radiation
- Earth-tides, 191
- eccentric anomaly, 288
- Einstein Equivalence Principle (EEP), 16–22; and cosmology, 312; implementation, 71; and nonsymmetric metric, 328; and speed of gravitational waves, 223; and speed of light, 223; and $TH_{\epsilon\mu}$ formalism, 46–50
- Einstein–Infeld–Hoffmann (EIH) formalism, 267; EIH Lagrangian, 269; *see also* modified EIH formalism
- energy conservation: and cyclic Gedanken experiments, 39–43; and Einstein Equivalence Principle, 39; in PPN formalism, 158–63; and Schiff's conjecture, 39–43; and Strong Equivalence Principle, 82; in $TH_{\epsilon\mu}$ formalism, 53–8
- Eötvös experiment, 24–7; and Belinfante–Swithart nonmetric theory, 66; and fifth force, 341; lunar, 185–90; and Nordtvedt effect, 185–90; Princeton and Moscow versions, 25; in space, 340
- Eöt–Wash experiment, 320
- equations of motion: charged test particles, 69; compact objects, *see* modified EIH formalism; Eulerian hydrodynamics, 87; n-body, 149, 159; Newtonian, for massive bodies, 145; photons, 143; PPN hydrodynamics, 147; self-gravitating bodies, 144–53; spinning bodies, 163–5; in $TH_{\epsilon\mu}$ formalism, 50
- equatorial coordinates, 194
- Eulerian equations of hydrodynamics, 87
- Fermi–Walker transport, 164
- fifth force, 341–3
- flat background metric, 79; in Robertson–Walker coordinates, 314
- gauge transformation, 96
- general covariance, 17; and preferred coordinate systems, 17; and prior geometry, 17
- general relativity, 121–3; black holes, 265; derivations of, 83; EIH formalism, 267; field equations, 121; locally measured gravitational constant in, 158; location in PPN theory space, 205; and modified EIH formalism, 275; motion of compact objects, 267; neutron stars, 260; Nordtvedt effect, 152; polarization of gravitational waves, 234; post-Newtonian limit, 121; PPN parameters, 122; quadrupole generation of gravitational waves, 246–8; with R^2 terms, 84–5; speed of gravitational waves, 223; standard cosmology, 316
- geocentric ecliptic coordinates, 192
- geodesic equation, 73; for compact objects, 267
- geometrical-optics limit: for gravitational waves, 223; for Maxwell's equations, 74–5
- gravimeter, 191; superconducting, 198
- gravitational constant, 120; constancy of, 202–4, 336; locally measured, 153–8, 191; in scalar–tensor theories, 124
- gravitational radiation: in binary pulsar, 297; detection in binary pulsar, 306, 346–7; dipole, 240, 249, 251, 279, 298; dipole parameter, 240, 253; E(2) classification, 226–7; effect on binary system, 239; energy flux in general relativity, 238; energy loss, 90, 238–40; forces in detectors, 237; in general relativity, 223, 234, 246; measurements of polarization, 237; measurement of speed, 226; in

- modified EIH formalism, 275;
 negative energy of, 252; PM
 parameters, 240, 253; polarization,
 227–38; post-Newtonian formalism,
 240; quadrupole nature in general
 relativity, 238; in Rastall's theory,
 225, 236; reaction force, 239; in
 Rosen's theory, 225, 236, 250; in
 scalar–tensor theories, 224, 234, 248,
 252, 279; speed, 223–6; speed in
 Rosen's theory, 131; in vector–tensor
 theories, 224, 235
 gravitational red shift, 5, 32–6, 322; in
 binary pulsar, 290, 296; and cyclic
 gedanken experiments, 42–3;
 derivation, 32–3; null experiment, 36;
 Pound–Rebka–Snider experiment, 33;
 in TH_{μ} formalism, 62–4; solar, 322;
 Vessor–Levine rocket experiment, 35
 gravitational stress-energy, 109, 241
 gravitational waveform, 238
 Gravitational Weak Equivalence Princi-
 ple (GWEP), 82; breakdown, 151, 185;
see also Nordtvedt effect
 gyroscope precession: derivation in PPN
 formalism, 208–9; dragging of inertial
 frames, 210; geodetic effect, 209, 338;
 and LAGEOS, 340; Lense–Thirring
 effect, 210; Stanford experiment, 212,
 252
 helicity of gravitational waves, 227, 232,
 252
 helium abundance, 315
 helium main-sequence star, 284, 294
 Hubble constant, 202, 313
 Hughes–Drever experiment, 30, 61
 hydrogenic atom in TH_{μ} formalism,
 55–7
 inertial mass, 13, 145; anomalous mass
 tensor, 40, 55, 162, 323; dependence
 on gravitational fields, 269; in
 modified EIH formalism, 273; post-
 Newtonian, 146
 isentropic flow, 106
 isotropic coordinates, 259
 J_2 , *see* quadrupole moment
 Kerr metric, 256
 Kreuzer experiment, 214
 laboratory experiments as tests of post-
 Newtonian gravity, 213
 Lagrangian-based metric theory, 78–9
 little group, 233
 local Lorentz invariance, 23; and
 propagation of light, 321;
 Hughes–Drever experiment, 30;
 kinematical frameworks, 325;
 Mansouri–Sextl framework, 325; tests
 of, 30–1, 320; tests using TH_{μ}
 formalism, 61–2; in TH_{μ} formalism,
 48, 323; violations of, 40–1
 local position invariance, 23; gravitational
 red-shift experiments, 32–6, 322; tests
 using TH_{μ} formalism, 62–4; in TH_{μ}
 formalism, 49; violations of, 40–1
 local quasi-Cartesian coordinates, 92
 local test experiment, 22
 Lorentz frames, local, 23
 Lorentz invariance: local, *see* local
 Lorentz invariance; of modified EIH
 Lagrangian, 272
 Lorentz transformations of null tetrad,
 232
 Lunar Laser Ranging Experiment
 (LURE), 188
 Mansouri–Sextl framework, 325
Mariner 6, 175
Mariner 7, 175
Mariner 9, 175
 mass, *see* active gravitational mass; iner-
 tial mass; passive gravitational mass
 mass function, 283
 Maxwell's equations, 72–3; ambiguity in
 curved spacetime, 72–3; geometrical-
 optics limit, 74–5; in TH_{μ} formalism,
 50
 metric, 22, 68; flat background, 79, 118;
 nonsymmetric, 328
 metric theories of gravity, postulates, 22;
see also theories of gravitation
 microwave background, 311, 314; Earth's
 motion relative to, 197
 Minkowski metric, 20, 80, 118
 modified EIH formalism: in Brans–Dicke
 theory, 276; equations of motion for
 binary systems, 273; in general relativity,
 275; gravitational radiation, 275;
 Keplerian orbits, 274; Lagrangian, 273;
 Newtonian limit, 274; periastron shift,
 274; in Rosen's theory, 280–2; variable
 inertial mass, 269
 moment of inertia of Earth, variation in,
 195
 momentum conservation: breakdown, in
 PPN formalism, 149; tests of, 215–20,
 337–8
 neutron stars, 255; boundary conditions,
 259; form of metric, 258; in general rel-
 ativity, 250; maximum mass, 256; mo-
 tion, *see* modified EIH formalism; in

Index

378

- Newtonian theory, 257–8; in Ni's theory, 263; in Rosen's theory, 261–3; in scalar–tensor theories, 260
- Newman–Penrose quantities, 230
- Newtonian gravitational potential, 87, 88, 151
- Newtonian limit, 21, 87, 145; conservation laws, 105; empirical evidence, 21; and fifth force, 341–3; inverse square force law, 21, 341–3; in modified EIH formalism, 274
- Newton's third law, 152; and Kreuzer experiment, 214; and lunar motion, 337
- Nordtved, K., Jr., 98
- Nordtved effect, 151; and lunar motion, 185–90; test of, using lunar laser ranging, 188–90; 335
- null separation, 74
- null tetrad, 229
- oblateness of Sun, 181; Dicke–Goldberg measurements, 181; Hill measurements, 182; and solar oscillations, 334
- Oklo natural reactor, 36–8
- orbit elements, Keplerian, 178, 283, 287; perturbation equations for, 179
- osculating orbit, 287
- parametrized post-Newtonian formalism, *see* PPN formalism
- particle physics, 20–1
- passive gravitational mass, 13; anomalous mass tensor, 40, 55, 58, 162; comparison with active mass, 214; in PPN formalism, 150
- perfect fluid, 77–8
- periastron shift: in binary pulsar, 284, 293; for compact objects, 274
- perihelion shift: derivation in PPN formalism, 177–80; measured, for Mercury, 181, 333; Mercury, 4, 176–83; preferred-frame and preferred-location effects, 200–1
- PM parameters, 240
- post-Coulombian expansion, 51
- post-Galilean transformation, 272
- post-Keplerian parameters, 343–4
- post-Newtonian limit: for gravitational-wave generation, 240–6; *see also* PPN formalism
- post-Newtonian potentials, 93, 104
- PPN formalism, 10, 97; active gravitational mass, 151; for charged particles, 214; Christoffel symbols, 144; comparison of different versions, 104; conservation-law parameters, 111; Edington–Robertson–Schiff version, 98; PPN ephemerides, 334; limits on PPN parameters, 204, 216, 219, 339; metric, 99, 104; n-body action principle, 158–60; n-body equations of motion, 149, 153; passive gravitational mass, 150; PPN parameters, 97; PPN parameter values for metric theories, 117; post-post-Newtonian extensions, 331; preferred-frame parameters, 103; significance of PPN parameters, 115; standard gauge, 97, 102
- preferred-frame effects: in Cavendish experiments, 148; geophysical tests, 190–9; on gyroscope precession, 210; in locally-measured gravitational constant, 190; orbital tests, 200–2, 336; and solar spin axis, 336; tests from Earth rotation rate, 199; tests using gravimeters, 199
- preferred-frame parameters: in PPN formalism, 103; in $\text{THE}\mu$ formalism, 48
- preferred-frame PPN parameters, limits on, 199, 202, 336, 339
- preferred-location effects: in Cavendish experiments, 148; geophysical tests, 190–9; in locally-measured gravitational constant, 190; orbital tests, 200–2; tests using gravimeters, 199
- prior geometry, 17, 79, 118
- projected semi-major axis, 293
- proper distance, 73, 155
- proper time, 73, 68
- PSR 1744–24A, 351
- PSR 1534 + 12, 347
- PSR 1913 + 15, *see* binary pulsar
- PSR 2127 + 11C, 347
- pulsars, 256, 283
- quadrupole moment, 145, 177; solar, 180; solar, measurable by *Solar Probe*, 183; and solar oscillations, 334
- quantum systems in $\text{THE}\mu$ formalism, 55–7
- quasi-local Lorentz frame, 80
- radar: active, 175; passive, 174; and time delay of light, 174
- radio interferometry and deflection of light, 172
- reduced field equations, 241
- rest frame of universe, 31, 99
- rest mass, total, 107
- retarded time, 228
- Ricci tensor, 73, 230
- Riemann curvature tensor, 72; electric components, 227; irreducible parts, 230

Index

379

- Riemann normal coordinates, 227
- Robertson–Walker metric, 91, 312
- Rosen's bimetric theory, 131; absence of black holes, 266; binary pulsar, 307; cosmological models, 317; field equations, 131; gravitational radiation, 225, 236, 250–2; location in PPN theory space, 205; and modified EIH formalism, 280; neutron stars, 261; post-Newtonian limit, 131; PPN parameters, 131
- rotation rate of Earth, variation in, 195
- scalar-tensor theories, 123–6; Barker's constant G theory 125; Bekenstein's variable-mass theory, 125, 317; Bergmann–Wagoner–Nordtvedt, 123; binary pulsar, 306; black holes, 265; Brans–Dicke, *see* Brans–Dicke theory; cosmological models, 317; field equation, 123; gravitational radiation, 224, 234, 248, 50; limits on ω , 175, 335; location in PPN theory space, 205; and modified EIH formalism, 276; neutron stars, 260; Nordtvedt effect, 152; post-Newtonian limit, 124; PPN parameters, 125; and string theory, 332
- Schiff, L. I., 38
- Schiff's conjecture, 38; proof in $\text{THE}\mu$ formalism, 50–3
- Schwarzschild coordinates, 259, 265
- Schwarzschild metric, 256, 265
- self-acceleration, 149; of binary system, 217, 338; of pulsars, 216
- self-consistency of gravitation theory, 19
- semi-latus rectum, 179
- Shapiro, I. I., 166
- Shapiro effect, *see* time delay of light solar corona, 172, 175
- Solar Probe*, 183, 340
- spacelike separation, 73
- special relativity, 20–1; agreement of gravitational theory with, 20–1; and propagation of light, 325–7; tests in particle physics, 20–1
- specific energy density, 89
- spin, 163; precession, 165; precession in binary pulsar, 302
- static spherical spacetimes, form of metric, 258
- stress-energy complex, 108
- stress-energy tensor, 76; in PPN formalism, 104; vanishing divergence of, 77
- Strong Equivalence Principle (SEP), 79–83; and dipole gravitational radiation, 252; and motion of compact objects, 268; tests of, 184, 335; violations in Cavendish experiments, 153; violations of, 102
- superpotential, 94
- $\text{THE}\mu$ formalism, 45–66; limitations, 58–9
- theories of gravitation: Barker's constant G theory, 125; Bekenstein's variable-mass-theory, 125, 317; Belinfante–Swihart, 64–6; Bergmann–Wagoner–Nordtvedt, 123; bimetric, 130–5; Brans–Dicke, *see* Brans–Dicke theory; BSLL bimetric theory, 133; conformally flat, 141; E(2) classes, 233–7; fully-conservative, 113; general relativity, *see* general relativity; Hellings–Nordtvedt, 130; Lagrangian-based, 43, 78–9, 109; linear fixed-gauge, 139; Moffat, 330; Ni, 137, 263; nonconservative theories, 115; nonviable, 19, 138–41; postulates of metric theories, 22; PPN parameters for, 117; purely dynamical vs. prior geometric, 79; quasilinear, 138; Rastall, 132, 225, 236, 318; Rosen, *see* Rosen's bimetric theory; scalar-tensor, *see* scalar-tensor theories; semiconservative, 114; special relativistic, 7; stratified, 135–7; stratified, with time-orthogonal space slices, 140; vector-tensor, *see* vector-tensor theories; Whitehead, 139; Will–Nordtvedt, 129; with nonsymmetric metric, 328–30
- time delay of light: in binary pulsar, 290; as classical test, 166; derivation in PPN formalism, 173–4; effect of solar corona, 175; measurements of, 174, 333; radar measurements, 176
- timelike separation, 73
- torsion, 84
- transverse-traceless projection, 248
- universal coupling, 43, 67–8
- vector-tensor theories, 126–30; field equations, 127; gravitational radiation, 224, 235; Hellings–Nordtvedt, 130; post-Newtonian limit, 129; PPN parameters, 129; Will–Nordtvedt, 129
- velocity curve, 283
- Viking*, 175, 336
- virial relations, 52, 54, 148, 161, 245
- Voyager 2*, 333
- Weak Equivalence Principle (WEP), 13, 22; and cyclic gedanken experiments,

Cambridge University Press

978-0-521-43973-2 - Theory and Experiment in Gravitational Physics, Revised Edition

Clifford M. Will

Index

[More information](#)*Index*

380

41–2; and electromagnetic interactions, 28–9; and Eötvös experiment, 24–7; and fifth force, 341; and gravitational interactions, 29, 82; of Newton, 13; and nonsymmetric metric, 329; and strong interactions, 28; tests of, 24–9,

320; tests using $\text{TH}_{\mu\nu}$ formalism, 60; and weak interactions, 29
 Weyl tensor, 230
 Whitehead PPN parameter, limits on, 199
 Whitehead's theory, 139
 Whitehead term, 95, 98