

Contents

Mass and Motion in General Relativity v

The Higgs Mechanism and the Origin of Mass 1

Abdelhak Djouadi

1 The Standard Model and the Generation of Particle Masses 1

1.1 The Elementary Particles and Their Interactions 2

1.2 The Standard Model of Particle Physics 3

1.3 The Higgs Mechanism for Mass Generation 5

2 The Profile of the Higgs Particle 8

2.1 Characteristics of the Higgs Boson 8

2.2 Constraints on the Higgs Boson Mass 9

2.3 The Higgs Decay Modes and Their Rates 11

3 Higgs Production at the LHC 13

3.1 The Large Hadron Collider 13

3.2 The Production of the Higgs Boson 14

3.3 Detection of the Higgs Boson 15

3.4 Determination of the Higgs Boson Properties 18

4 The Higgs Beyond the Standard Model 20

5 Conclusions 22

References 23

Testing Basic Laws of Gravitation – Are Our Postulates on Dynamics and Gravitation Supported by Experimental Evidence? 25

Claus Lämmerzahl

1 Introduction – Why Gravity Is so Exceptional 25

2 Key Features of Gravity 27

3 Standard Tests of the Foundations of Special and General Relativity 28

3.1 Tests of Special Relativity 28

3.2 Tests of the Universality of Free Fall 30

3.3 Tests of the Universality of the Gravitational Redshift 31

3.4 The Consequence 32

4	Tests of Predictions	34
4.1	The Gravitational Redshift.....	35
4.2	Light Deflection	36
4.3	Perihelion/Periastron Shift	37
4.4	Gravitational Time Delay	38
4.5	Lense–Thirring Effect.....	40
4.6	Schiff Effect	41
4.7	The Strong Equivalence Principle	41
5	Why New Tests?	42
5.1	Dark Clouds – Problems with GR	42
5.2	The Search for Quantum Gravity	45
5.3	Possible New Effects	45
6	How to Search for “New Physics”	46
6.1	Better Accuracy and Sensitivity	46
6.2	Extreme Situations	47
6.3	Investigation of “Exotic” Issues	49
7	Testing “Exotic” but Fundamental Issues	50
7.1	Active and Passive Mass	50
7.2	Active and Passive Charge	51
7.3	Active and Passive Magnetic Moment	52
7.4	Charge Conservation	52
7.5	Small Accelerations	53
7.6	Test of the Inertial Law	54
7.7	Can Gravity Be Transformed Away?	57
8	Summary	60
	References	60

Mass Metrology and the International System of Units (SI) 67

Richard S. Davis

1	Introduction	67
2	The SI.....	68
2.1	Base Units/Base Quantities	68
2.2	Gaussian Units.....	70
2.3	Planck Units, Natural Units, and Atomic Units.....	71
3	Practical Reasons for Redefining the Kilogram	71
3.1	Internal Evidence Among 1 kg Artifact Mass Standards.....	71
3.2	Fundamental Constants	73
3.3	Electrical Metrology	75
3.4	Relative Atomic Masses	77
4	Routes to a New Kilogram	78
5	Realizing a New Kilogram Definition in Practice	79
5.1	Watt Balances	80
5.2	Silicon X-Ray Crystal Density (XRCD)	81
5.3	Experimental Results.....	82

6	Proposals for a New SI	83
6.1	Consensus Building and Formal Approval	83
6.2	An SI Based on Defined Values of a Set of Constants	84
7	Conclusion	84
	References	85

Mass and Angular Momentum in General Relativity 87

José Luis Jaramillo and Ericourgoulhon

1	Issues Around the Notion of Gravitational Energy in General Relativity ...	88
1.1	Energy–Momentum Density for Matter Fields	88
1.2	Problems when Defining a Gravitational Energy–Momentum	90
1.3	Notation	92
2	Spacetimes with Killing Vectors: Komar Quantities	94
2.1	Komar Mass	94
2.2	Komar Angular Momentum	95
3	Total Mass of Isolated Systems in General Relativity	95
3.1	Asymptotic Flatness Characterization of Isolated Systems	95
3.2	Asymptotic Euclidean Slices	96
3.3	ADM Quantities	97
3.4	Bondi Energy and Linear Momentum	105
4	Notions of Mass for Bounded Regions: Quasi-Local Masses	108
4.1	Ingredients in the Quasi-Local Constructions	108
4.2	Some Relevant Quasi-Local Masses	109
4.3	Some Remarks on Quasi-Local Angular Momentum	114
4.4	A Study Case: Quasi-Local Mass of Black Hole IHs	115
5	Global and Quasi-Local Quantities in Black Hole Physics	118
5.1	Penrose Inequality: a Claim for an Improved Mass Positivity Result for Black Holes	119
5.2	Black Hole (Thermo-)dynamics	119
5.3	Black Hole Extremality: a Mass–Angular Momentum Inequality ...	121
6	Conclusions	121
	References	123

Post-Newtonian Theory and the Two-Body Problem 125

Luc Blanchet

1	Introduction	125
2	Post-Newtonian Formalism	128
2.1	Einstein Field Equations	128
2.2	Post-Newtonian Iteration in the Near Zone	131
2.3	Post-Newtonian Expansion Calculated by Matching	135
2.4	Multipole Moments of a Post-Newtonian Source	139
2.5	Radiation Field and Polarization Waveforms	143
2.6	Radiative Moments Versus Source Moments	145

3	Inspiralling Compact Binaries	147
3.1	Stress–Energy Tensor of Spinning Particles	147
3.2	Hadamard Regularization	150
3.3	Dimensional Regularization	153
3.4	Energy and Flux of Compact Binaries	156
3.5	Waveform of Compact Binaries	160
3.6	Spin–Orbit Contributions in the Energy and Flux	162
	References	164

Post-Newtonian Methods: Analytic Results on the Binary

Problem	167
Gerhard Schäfer	
1 Introduction	167
2 Systems in Newtonian Gravity in Canonical Form.....	169
3 Canonical General Relativity and PN Expansions	171
3.1 Canonical Variables of the Gravitational Field	173
3.2 Brill–Lindquist Initial-Value Solution for Binary Black Holes	175
3.3 Skeleton Hamiltonian	176
3.4 Functional Representation of Compact Objects	179
3.5 PN Expansion of the Routh Functional	185
3.6 Near-Zone Energy Loss Versus Far-Zone Energy Flux	185
4 Binary Point Masses to Higher PN Order	187
4.1 Conservative Hamiltonians	187
4.2 Dynamical Invariants.....	188
4.3 ISCO and the PN Framework.....	190
4.4 PN Dissipative Binary Dynamics.....	192
5 Toward Binary Spinning Black Holes	192
5.1 Approximate Hamiltonians for Spinning Binaries.....	196
6 Lorentz-Covariant Approach and PN Expansions.....	200
6.1 PM and PN Expansions	202
6.2 PN Expansion in the Near Zone	203
6.3 PN Expansion in the Far Zone.....	205
7 Energy Loss and Gravitational Wave Emission	206
7.1 Orbital Decay to 4 PN Order	206
7.2 Gravitational Waveform to 1.5 PN Order	207
References	209

The Effective One-Body Description of the Two-Body Problem

Thibault Damour and Alessandro Nagar

1	Introduction	211
2	Motion and Radiation of Binary Black Holes: PN Expanded Results	213
3	Conservative Dynamics of Binary Black Holes: the EOB Approach	215
4	Description of Radiation–Reaction Effects in the EOB Approach	224
4.1	Resummation of \hat{F}^{Taylor} Using a One-Parameter Family of Padé approximants: Tuning v_{pole}	227
4.2	Parameter-Free Resummation of Waveform and Energy Flux	230

5	EOB Dynamics and Waveforms	238
5.1	Post-Post-Circular Initial Data	238
5.2	EOB Waveforms	239
5.3	EOB Dynamics	241
6	EOB and NR Waveforms	243
7	Conclusions	248
	References	249

Introduction to Gravitational Self-Force

Robert M. Wald

1	Motion of Bodies in General Relativity	253
2	Point Particles in General Relativity	254
3	Point Particles in Linearized Gravity	255
4	Lorenz Gauge Relaxation	256
5	Hadamard Expansions	256
5.1	Hadamard Expansions for a Point Particle Source	258
6	Equations of Motion Including Self-Force	259
6.1	The MiSaTaQuWa Equations	259
6.2	The Detweiler-Whiting Reformulation	260
7	How Should Gravitational Self-Force Be Derived?	261
	References	262

Derivation of Gravitational Self-Force

Samuel E. Gralla and Robert M. Wald

1	Difficulties with Usual Derivations	263
2	Rigorous Derivation Requirements	264
3	Limits of Spacetimes	264
4	Our basic Assumptions	265
4.1	Additional Uniformity Requirement	265
5	Geodesic Motion	266
6	Corrections to Motion	267
6.1	Calculation of the Perturbed Motion	268
7	Interpretation of Results	269
8	Self-Consistent Equations	269
9	Summary	270
	References	270

Elementary Development of the Gravitational Self-Force

Steven Detweiler

1	Introduction	271
1.1	Outline	273
1.2	Notation	274
2	Newtonian Examples of Self-Force and Gauge Issues	275
3	Classical Electromagnetic Self-Force	277

4	A Toy Problem with Two Length Scales That Creates a Challenge for Numerical Analysis	278
4.1	An Approach Which Avoids the Small Length Scale	279
4.2	An Alternative That Resolves Boundary Condition Issues	281
5	Perturbation Theory	282
5.1	Standard Perturbation Theory in General Relativity	283
5.2	An Application of Perturbation Theory: Locally Inertial Coordinates	285
5.3	Metric Perturbations in the Neighborhood of a Point Mass	287
5.4	A Small Object Moving Through Spacetime	289
6	Self-Force from Gravitational Perturbation Theory	291
6.1	Dissipative and Conservative Parts	292
6.2	Gravitational Self-Force Implementations	293
7	Perturbative Gauge Transformations	295
8	Gauge Confusion and the Gravitational Self-Force	297
9	Steps in the Analysis of the Gravitational Self-Force	298
10	Applications	300
10.1	Gravitational Self-Force Effects on Circular Orbits of the Schwarzschild Geometry	300
10.2	Field Regularization Via the Effective Source	301
11	Concluding Remarks	304
	References	306

Constructing the Self-Force

Eric Poisson

1	Introduction	309
2	Geometric Elements	311
3	Coordinate Systems	312
4	Field Equation and Particle Motion	316
5	Retarded Green's Function	316
6	Alternate Green's Function	318
7	Fields Near the World Line	319
8	Self-Force	321
9	Axiomatic Approach	322
10	Conclusion	324
	References	325

Computational Methods for the Self-Force in Black Hole

Spacetimes

Leor Barack

1	Introduction and Overview	327
1.1	The MiSaTaQuWa Formula	329
1.2	Gauge Dependence	330
1.3	Implementation Strategies	331

2	Mode-Sum Method	335
2.1	An Elementary Example	336
2.2	The Mode-Sum Formula	338
2.3	Derivation of the Regularization Parameters	339
3	Numerical Implementation Strategies	343
3.1	Overcoming the Gauge Problem	344
3.2	Numerical Representation of the Point Particle	347
4	An Example: Gravitational Self-Force in Schwarzschild Via 1+1D Evolution in Lorenz Gauge	352
4.1	Lorenz-Gauge Formulation	352
4.2	Numerical Implementation	354
5	Toward Self-Force Calculations in Kerr: the Puncture Method and m -Mode Regularization	356
5.1	Puncture Method in 2+1D	356
5.2	m -Mode Regularization	358
6	Reflections and Prospects	360
	References	364

Radiation Reaction and Energy–Momentum Conservation.....367

Dmitri Gal'tsov

1	Introduction	367
2	Energy–Momentum Balance Equation	369
2.1	Decomposition of the Stress Tensor	371
2.2	Bound Momentum	374
2.3	The Rest Frame (Nonrelativistic Limit)	377
3	Flat Dimensions Other than Four	378
4	Local Method for Curved Space-Time	379
4.1	Hadamard Expansion in Any Dimensions	380
4.2	Divergences	381
4.3	Four Dimensions	384
4.4	Self and Radiative Forces in Curved Space-Time	386
5	Gravitational Radiation	387
5.1	Bianchi Identity	387
5.2	Vacuum Background	389
5.3	Gravitational Radiation for Non-Geodesic Motion	390
6	Conclusions	391
	References	392

The State of Current Self-Force Research.....395

Lior M. Burko

1	Introduction	395
2	The Teukolsky Equation	397
2.1	The Inhomogeneous Teukolsky Equation with a Distributional Source	397
2.2	Adiabatic Waveforms	398

2.3	Numerical Solution of the Teukolsky Equation	399
2.4	The Linearized Einstein Equations	400
3	Frequency-Domain Calculations of the Self-Force	401
3.1	Mode-Sum Regularization	401
3.2	The Detweiler–Whiting Regular Part of the Self-Force	402
4	Time-Domain Calculations of the Self-Force	403
4.1	1+1D Numerical Simulations	403
4.2	2+1D Numerical Simulations	404
5	Post-adiabatic Self-Force-Driven Orbital Evolution	408
5.1	The Importance of Second-Order Self-Forces	408
5.2	Conservative Self-Force Effects	412
	References	413

High-Accuracy Comparison Between the Post-Newtonian and Self-Force Dynamics of Black-Hole Binaries415

Luc Blanchet, Steven Detweiler, Alexandre Le Tiec,
and Bernard F. Whiting

1	Introduction and Motivation	416
2	The Gauge-Invariant Redshift Observable	418
3	Regularization Issues in the SF and PN Formalisms	419
4	Circular Orbits in the Perturbed Schwarzschild Geometry	421
5	Overview of the 3PN Calculation	423
5.1	Iterative PN Computation of the Metric	423
5.2	The Example of the Zeroth-Order Iteration	426
6	Logarithmic Terms at 4PN and 5PN Orders	427
6.1	Physical Origin of Logarithmic Terms	427
6.2	Expression of the Near-Zone Metric	429
7	Post-Newtonian Results for the Redshift Observable	430
8	Numerical Evaluation of Post-Newtonian Coefficients	433
8.1	Overview	434
8.2	Framework for Evaluating PN Coefficients Numerically	435
8.3	Consistency Between Analytically and Numerically Determined PN Coefficients	437
8.4	Determining Higher Order PN Terms Numerically	438
8.5	Summary	439
	References	441

LISA and Capture Sources.....443

Oliver Jennrich

1	LISA – A Mission to Detect and Observe Gravitational Waves	443
1.1	Mission Concept	444
1.2	Sensitivity	445
1.3	Measurement Principle	446
2	Capture Sources	448
3	Science Return	449

4	Detection	451
4.1	Capture Rates	451
4.2	Signal Characteristics	452
4.3	Data Analysis	454
5	Summary and Conclusions	456
	References	457

Motion in Alternative Theories of Gravity461

Gilles Esposito-Farèse

1	Introduction	461
2	Modifying the Matter Action	462
3	Modified Motion in Metric Theories?	464
4	Scalar-Tensor Theories of Gravity	468
4.1	Weak-Field Predictions	469
4.2	Strong-Field Predictions	471
4.3	Binary-Pulsar Tests	472
4.4	Black Holes in Scalar-Tensor Gravity	476
5	Extended Bodies	477
6	Modified Newtonian Dynamics	479
6.1	Mass-Dependent Models?	480
6.2	Aquadratic Lagrangians or k-Essence	481
6.3	Difficulties	482
6.4	Nonminimal Couplings	485
7	Conclusions	486
	References	487

Mass, Inertia, and Gravitation491

Marc-Thierry Jaekel and Serge Reynaud

1	Introduction	491
2	Vacuum Fluctuations and Inertia	494
2.1	Linear Response Formalism	494
2.2	Response to Motions	498
2.3	Relativity of Motion	502
2.4	Inertia of Vacuum Fields	504
3	Mass as a Quantum Observable	508
3.1	Quantum Fluctuations of Mass	508
3.2	Mass and Conformal Symmetries	510
4	Metric Extensions of GR	514
4.1	Radiative Corrections	515
4.2	Anomalous Curvatures	518
4.3	Phenomenology in the Solar System	520
5	Conclusion	526
	References	527

Motion in Quantum Gravity	531
Karim Noui	
1 Introduction	531
1.1 The Problem of Defining Motion in Quantum Gravity	531
1.2 Quantum Gravity	532
1.3 Three-Dimensional Quantum Gravity Is a Fruitful Toy Model	534
1.4 Outline of the Article.....	535
2 Casting an Eye Over Loop Quantum Gravity	536
2.1 The Classical Theory: Main Ingredients	536
2.2 The Route to the Quantization of Gravity	538
2.3 Spin-Networks Are States of Quantum Geometry	539
2.4 The Problem of the Hamiltonian Constraint	541
3 Three-Dimensional Euclidean Quantum Gravity	542
3.1 Construction of the Noncommutative Space	543
3.2 Constructing the Quantum Dynamics	550
3.3 Particles Evolving in the Fuzzy Space	552
3.4 Reduction to One Dimension	553
4 Discussion	558
References	559
 Free Fall and Self-Force: an Historical Perspective	 561
Alessandro Spallicci	
1 Introduction	562
2 The Historical Heritage	563
3 Uniqueness of Acceleration and the Newtonian Back-Action	565
4 The Controversy on the Repulsion and on the Particle Velocity at the Horizon	569
5 Black Hole Perturbations	574
6 Numerical Solution	578
7 Relativistic Radial Fall Affected by the Falling Mass	582
7.1 The Self-Force	582
7.2 The Pragmatic Approach.....	587
8 The State of the Art	590
8.1 Trajectory	591
8.2 Regularisation Parameters	592
8.3 Effect of Radiation Reaction on the Waveforms During Plunge	592
9 Beyond the State of the Art: the Self-Consistent Prescription	593
10 Conclusions	595
References	597
 Index	 605



<http://www.springer.com/978-90-481-3014-6>

Mass and Motion in General Relativity

Blanchet, L.; Spallicci, A.; Whiting, B. (Eds.)

2011, XVIII, 626 p., Hardcover

ISBN: 978-90-481-3014-6