

Contents

<i>Preface</i>	page ix
<i>Constants</i>	xiii
<i>Notation</i>	xv
1 Newton's gravitational theory	1
1.1 The law of universal gravitation	1
1.2 Tests of the inverse-square law	4
1.3 Gravitational potential	11
1.4 Gravitational multipoles; quadrupole moment of the Sun	13
1.5 Inertial and gravitational mass	17
1.6 Tests of equality of gravitational and inertial mass	19
1.7 Tidal forces	29
1.8 Tidal field as a local measure of gravitation	34
Problems	42
References	45
2 The formalism of special relativity	47
2.1 The spacetime of special relativity	48
2.2 Tensors in spacetime	55
2.3 Tensor fields	62
2.4 Energy-momentum tensor	64
2.5 Relativistic electrodynamics	71
2.6 Differential forms and exterior calculus	76
Problems	87
References	94
3 The linear approximation	95
3.1 The example of electromagnetism	95
3.2 Linear field equations for gravitation	101
3.3 Variational principle and equation of motion	106
3.4 Nonrelativistic limit and Newton's theory	112
3.5 Geometric interpretation; curved spacetime	117
Problems	123
References	126

4 Applications of the linear approximation	127
4.1 Field of a spherical mass	127
4.2 Gravitational time dilation	130
4.3 Deflection of light	138
4.4 Time delay of light	142
4.5 Gravitational lenses	149
4.6 Optics of gravitational lenses	159
4.7 Field of a rotating mass; Lense-Thirring effect	164
Problems	170
References	180
5 Gravitational waves	182
5.1 Plane waves	182
5.2 Interaction of particles with a gravitational wave	187
5.3 Emission of gravitational radiation	191
5.4 Emission by a vibrating quadrupole	196
5.5 Emission by a rotating quadrupole	199
5.6 Emission of bursts of gravitational radiation	204
5.7 Detectors of gravitational radiation	208
Problems	215
References	220
6 Riemannian geometry	221
6.1 General coordinates and tensors	223
6.2 Parallel transport; covariant derivative	226
6.3 Geodesic equation	232
6.4 Metric tensor	236
6.5 Riemann curvature tensor	243
6.6 Geodesic deviation and tidal forces; Fermi-Walker transport	252
6.7 Differential forms in curved spacetime	257
6.8 Isometries of spacetime; Killing vectors	262
Problems	268
References	274
7 Einstein's gravitational theory	275
7.1 General covariance and invariance; gauge transformations	276
7.2 Einstein's field equation	284
7.3 Another approach to Einstein's equation; cosmological term	288
7.4 Schwarzschild solution and Birkhoff theorem	293
7.5 Motion of planets; perihelion precession	299
7.6 Propagation of light; gravitational redshift	305
7.7 Geodetic precession	309
Problems	317
References	322

8 Black holes and gravitational collapse	324
8.1 Singularities and pseudosingularities	325
8.2 The black hole and its horizon	329
8.3 Maximal Schwarzschild geometry	335
8.4 Kerr solution and Reissner-Nordstrøm solution	343
8.5 Horizons and singularities of the rotating black hole	349
8.6 Maximal Kerr geometry	356
8.7 Black-hole thermodynamics; Hawking process	360
8.8 Gravitational collapse and formation of black holes	367
8.9 In search of black holes	375
Problems	381
References	387
9 Cosmology	389
9.1 Large-scale structure of the universe	390
9.2 Cosmic distances	392
9.3 Expansion of the universe; Hubble's law	394
9.4 Age of the universe	401
9.5 Cosmic background radiation	404
9.6 Mass density; dark mass	408
9.7 Comoving coordinates; Robertson-Walker geometry	411
9.8 Friedmann models ($\rho \neq 0, \Lambda = 0$)	418
9.9 Empty Lemaître models ($\rho = 0, \Lambda \neq 0$)	424
9.10 Friedmann-Lemaître models ($\rho \neq 0, \Lambda \neq 0$)	426
9.11 Propagation of light; particle horizon	428
9.12 Comparison of theory and observation	434
Problems	437
References	442
10 The early universe	444
10.1 Temperature of the early universe	445
10.2 Nucleosynthesis; abundance of primordial helium	451
10.3 Density perturbations; Jeans mass	456
10.4 Inflationary model	462
Problems	473
References	476
Appendix: Variational principle and energy-momentum tensor	477
A.1 Lagrange equations for a system of particles	477
A.2 Lagrange equations for fields	479
A.3 Energy-momentum tensor	482
A.4 Variational principle for Einstein's equations	486
A.5 Flux theorem and its implications for gravitational and inertial mass	491
References	496
<i>Answers to even-numbered problems</i>	497
<i>Index</i>	503