

Contents

1	Introduction	1
1.1	Problems in Newtonian Cosmology.	2
1.2	The Standard Model of Cosmology.	3
1.2.1	Hubble's Law.	6
1.2.2	Big Bang Nucleosynthesis	7
1.2.3	Cosmic Microwave Background	8
1.3	Evidence for New Physics	9
1.3.1	Inflation.	10
1.3.2	Baryogenesis	11
1.3.3	Dark Matter	12
1.3.4	Cosmological Constant Problems	13
1.4	Age and Size of the Universe.	14
1.5	Cosmological Models Beyond General Relativity	16
	References.	16
2	General Relativity	17
2.1	Scalars, Vectors and Tensors	17
2.2	Geodesic Equations.	20
2.2.1	Newtonian Mechanics	20
2.2.2	Relativistic Mechanics	21
2.3	Energy and Momentum in Flat Spacetime	23
2.4	Energy-Momentum Tensor in Flat Spacetime	24
2.5	Curved Spacetime.	26
2.6	Field Theory in Flat and Curved Spacetimes	27
2.7	Einstein Equations	29
	Problems.	32
	References.	33

3	The Standard Model of Particle Physics	35
3.1	Fermions	37
3.1.1	Leptons	38
3.1.2	Quarks	38
3.2	Bosons	39
3.2.1	Gauge Bosons	39
3.2.2	Higgs Particle.	41
3.3	Feynman Diagrams	42
3.4	Beyond the Minimal Standard Model of Particle Physics	44
3.4.1	Supersymmetric Models.	45
3.4.2	Grand Unification Theories	46
3.4.3	Heavy Neutrinos.	48
3.4.4	Peccei-Quinn Model	49
3.5	Probabilities of Reactions Among Particles	49
	Problems.	52
	References.	52
4	Cosmological Models	53
4.1	Friedmann-Robertson-Walker Metric	54
4.2	Friedmann Equations.	56
4.3	Cosmological Models	57
4.3.1	Einstein Universe	58
4.3.2	Matter Dominated Universe	58
4.3.3	Radiation Dominated Universe	60
4.3.4	Vacuum Dominated Universe.	61
4.4	Basic Properties of the FRW Metric	62
4.5	Age of the Universe	64
4.6	Λ CDM Model	65
4.7	Destiny of the Universe.	68
	Problems.	70
	References.	70
5	Kinetics and Thermodynamics in Cosmology	71
5.1	Introduction	71
5.2	Thermal Equilibrium in the Early Universe	71
5.2.1	General Features.	71
5.2.2	Kinetic Equation.	76
5.2.3	Plasma Heating and Entropy Conservation.	80
5.3	Freezing of Species.	82
5.3.1	Decoupling and Gershtein-Zeldovich Bound.	82
5.3.2	Freezing of Non-relativistic Particles	86
5.4	Neutrino Spectrum and Effective Number of Neutrino Species.	90
	Problems.	92
	References.	92

6	Inflation	93
6.1	Introduction and History	93
6.2	Problems of Pre-inflationary Cosmology	94
6.2.1	Kinematics and Main Features of Inflation	95
6.2.2	Flatness Problem	96
6.2.3	Horizon Problem	96
6.2.4	Origin of the Cosmological Expansion	98
6.2.5	Smoothing Down the Universe and Creation of Primordial Density Perturbations	98
6.2.6	Magnetic Monopole Problem	99
6.3	Mechanisms of Inflation	101
6.3.1	Canonical Scalar Inflaton with Power Law Potential	101
6.3.2	Other Mechanisms of Inflation	103
6.4	Universe Heating	105
6.4.1	Perturbative Production	106
6.4.2	Non-perturbative Phenomena	109
6.4.3	Parametric Resonance	112
6.4.4	Particle Production in a Gravitational Field	115
6.5	Generation of Gravitational Waves	117
6.6	Generation of Density Perturbations	121
	References	125
7	Baryogenesis	127
7.1	Observational Data	127
7.2	General Features of Baryogenesis Models	129
7.2.1	Sakharov Principles	129
7.2.2	CP Breaking in Cosmology	131
7.3	Models of Baryogenesis	132
7.3.1	Baryogenesis by Heavy Particle Decays	133
7.3.2	Electroweak Baryogenesis	135
7.3.3	Baryo-Through-Leptogenesis	138
7.3.4	Evaporation of Primordial Black Holes	139
7.3.5	Spontaneous Baryogenesis	143
7.3.6	Baryogenesis by Condensed Scalar Baryons	149
7.4	Cosmological Antimatter	151
	Problems	156
	References	156
8	Big Bang Nucleosynthesis	161
8.1	Light Elements in the Universe	162
8.2	Freeze-Out of Weak Interactions	163
8.3	Electron-Positron Annihilation	165
8.4	Deuterium Bottleneck	166

8.5	Primordial Nucleosynthesis	168
8.6	Baryon Abundance	170
8.7	Constraints on New Physics	171
	Problems	173
	References	173
9	Dark Matter	175
9.1	Observational Evidence	176
9.2	Dark Matter Candidates	178
9.2.1	Lightest Supersymmetric Particle	180
9.2.2	Axion	181
9.2.3	Super-Heavy Particles	181
9.2.4	Primordial Black Holes	182
9.3	Direct Search for Dark Matter Particles	183
9.4	Indirect Search for Dark Matter Particles	187
	Problems	188
	References	188
10	Cosmic Microwave Background	191
10.1	Recombination and Decoupling	192
10.2	Formalism for the Description of Fluctuations	193
10.3	Anisotropies of the CMB	198
10.3.1	Primary Anisotropies	198
10.3.2	Secondary Anisotropies	200
10.3.3	Polarization Anisotropies	200
10.4	Primordial Perturbations	203
10.5	Determination of the Cosmological Parameters	204
	Problems	205
	References	205
11	Dark Energy	207
11.1	Cosmological Acceleration	207
11.1.1	Astronomical Data	209
11.1.2	Acceleration by a Scalar Field	211
11.1.3	Modified Gravity	212
11.2	Problem of Vacuum Energy	213
	References	215
12	Density Perturbations	217
12.1	Density Perturbations in Newtonian Gravity	217
12.2	Density Perturbations in General Relativity	223
12.2.1	Metric and Curvature	223
12.2.2	Energy-Momentum Tensor	224
12.2.3	Choice of Gauge	225

- 12.2.4 Evolution of Perturbations in Asymptotically Flat Spacetime 227
- 12.2.5 Evolution of Perturbations in Cosmology. 228
- 12.2.6 Concluding Remarks 235
- 12.3 Density Perturbations in Modified Gravity 236
 - 12.3.1 General Equations. 236
 - 12.3.2 Modified Jeans Instability 241
 - 12.3.3 Effects of Time Dependent Background. 243
- Problems. 243
- References. 244

- Appendix A: Natural Units 245**

- Appendix B: Gauge Theories 247**

- Appendix C: Field Quantization 249**



<http://www.springer.com/978-3-662-48077-9>

Introduction to Particle Cosmology
The Standard Model of Cosmology and its Open
Problems

Bambi, C.; Dolgov, A.D.

2016, XI, 251 p. 30 illus., 21 illus. in color., Hardcover

ISBN: 978-3-662-48077-9