

Contents

	<i>Preface</i>	<i>page</i> ix
1	The homogeneous and isotropic universe	1
1.1	Homogeneity and isotropy	2
1.2	The background geometry of the Universe	3
1.3	Recombination and decoupling	14
1.4	Nucleosynthesis	27
1.5	Inflation	42
2	Perturbation theory	57
2.1	Introduction	57
2.2	Gauge-invariant perturbation variables	58
2.3	The perturbation equations	70
2.4	Simple examples	80
2.5	Light-like geodesics and CMB anisotropies	87
2.6	Power spectra	92
2.7	Final remarks	102
3	Initial conditions	105
3.1	Scalar field perturbations	106
3.2	Generation of perturbations during inflation	111
3.3	Mixture of dust and radiation revisited	121
4	CMB anisotropies	134
4.1	Introduction to kinetic theory	134
4.2	The Liouville equation in a perturbed FL universe	139
4.3	The energy–momentum tensor	143
4.4	The ultra-relativistic limit, the Liouville equation for massless particles	149
4.5	The Boltzmann equation	156
4.6	Silk damping	169
4.7	The full system of perturbation equations	171

viii	<i>Contents</i>	
5	CMB polarization and the total angular momentum approach	176
5.1	Polarization dependent Thomson scattering	177
5.2	Total angular momentum decomposition	183
5.3	The spectra	188
5.4	The small-scale limit and the physical meaning of \mathcal{E} and \mathcal{B}	194
5.5	The Boltzmann equation	199
6	Cosmological parameter estimation	210
6.1	Introduction	210
6.2	The physics of parameter dependence	211
6.3	Reionization	216
6.4	CMB data	217
6.5	Statistical methods	224
6.6	Degeneracies	245
6.7	Complementary observations	251
6.8	Sources	265
7	Lensing and the CMB	278
7.1	An introduction to lensing	278
7.2	The lensing power spectrum	282
7.3	Lensing of the CMB temperature anisotropies	283
7.4	Lensing of the CMB polarization	290
7.5	Non-Gaussianity	300
7.6	Other second-order effects	301
8	The CMB spectrum	304
8.1	Collisional processes in the CMB	304
8.2	A chemical potential	318
8.3	The Sunyaev–Zel’dovich effect	320
Appendix 1	Fundamental constants, units and relations	326
Appendix 2	General relativity	330
Appendix 3	Perturbations	335
Appendix 4	Special functions	340
Appendix 5	Entropy production and heat flux	357
Appendix 6	Mixtures	362
Appendix 7	Statistical utensils	364
Appendix 8	Approximation for the tensor C_ℓ spectrum	370
Appendix 9	Boltzmann equation in a universe with curvature	375
Appendix 10	The solutions of some exercises	384
	<i>References</i>	392
	<i>Index</i>	399