

Table of Contents

“The most technologically efficient machine that man has invented is the book.”

Northrop Frye

Preface	V
1 Historical Introduction	1
1.1 Discoveries in the 20th Century	3
1.2 Discoveries of New Elementary Particles	8
1.3 Start of the Satellite Era	11
1.4 Open Questions	17
1.5 Problems	19
2 The Standard Model of Elementary Particles	21
2.1 Examples of Interaction Processes	26
2.2 Problems	33
3 Kinematics and Cross Sections	35
3.1 Threshold Energies	37
3.2 Four-Vectors	39
3.3 Lorentz Transformation	44
3.4 Cross Sections	46
3.5 Problems	47
4 Physics of Particle and Radiation Detection	49
4.1 Interactions of Astroparticles	50
4.2 Interaction Processes Used for Particle Detection	51
4.3 Principles of the Atmospheric Air Cherenkov Technique	55
4.4 Special Aspects of Photon Detection	56
4.5 Cryogenic Detection Techniques	58
4.6 Propagation and Interactions of Astroparticles in Galactic and Extragalactic Space	58
4.7 Characteristic Features of Detectors	60
4.8 Problems	61

Acceleration Mechanisms	63
5.1 Cyclotron Mechanism	64
5.2 Acceleration by Sunspot Pairs	65
5.3 Shock Acceleration	66
5.4 Fermi Mechanism	68
5.5 Pulsars	69
5.6 Binaries	71
5.7 Energy Spectra of Primary Particles	73
5.8 Problems	76
Primary Cosmic Rays	77
6.1 Charged Component of Primary Cosmic Rays	78
6.2 Neutrino Astronomy	86
6.2.1 Atmospheric Neutrinos	88
6.2.2 Solar Neutrinos	94
6.2.3 Supernova Neutrinos	100
6.2.4 High-Energy Galactic and Extragalactic Neutrinos	104
6.3 Gamma Astronomy	108
6.3.1 Introduction	108
6.3.2 Production Mechanisms for γ Rays	110
6.3.3 Measurement of γ Rays	113
6.3.4 Observation of γ -Ray Point Sources	117
6.3.5 γ Burster	120
6.4 X-Ray Astronomy	123
6.4.1 Introduction	123
6.4.2 Production Mechanisms for X Rays	124
6.4.3 Detection of X Rays	126
6.4.4 Observation of X-Ray Sources	128
6.5 Gravitational-Wave Astronomy	133
6.6 Problems	136
Secondary Cosmic Rays	141
7.1 Propagation in the Atmosphere	142
7.2 Cosmic Rays at Sea Level	147
7.3 Cosmic Rays Underground	151
7.4 Extensive Air Showers	156
7.5 Nature and Origin of the Highest-Energy Cosmic Rays	163
7.6 Problems	169

8	Cosmology	171
8.1	The Hubble Expansion	173
8.2	The Isotropic and Homogeneous Universe	175
8.3	The Friedmann Equation from Newtonian Gravity	177
8.4	The Friedmann Equation from General Relativity	179
8.5	The Fluid Equation	182
8.6	The Acceleration Equation	183
8.7	Nature of Solutions to the Friedmann Equation	183
8.8	Experimental Evidence for the Vacuum Energy	186
8.9	Problems	189
9	The Early Universe	191
9.1	The Planck Scale	191
9.2	Thermodynamics of the Early Universe	193
9.2.1	Energy and Number Densities	194
9.2.2	The Total Energy Density	195
9.2.3	Equations of State	198
9.2.4	Relation between Temperature and Scale Factor	199
9.3	Solving the Friedmann Equation	199
9.3.1	Digression on Thermal Equilibrium	202
9.4	Thermal History of the First Ten Microseconds	203
9.5	The Baryon Asymmetry of the Universe	205
9.5.1	Experimental Evidence of Baryon Asymmetry	206
9.5.2	Size of the Baryon Asymmetry	208
9.5.3	The Sakharov Conditions	209
9.6	Problems	211
10	Big Bang Nucleosynthesis	213
10.1	Some Ingredients for BBN	214
10.2	Start of the BBN Era	215
10.3	The Neutron-to-Proton Ratio	216
10.4	Neutrino Decoupling, Positron Annihilation, and Neutron Decay	218
10.5	Synthesis of Light Nuclei	220
10.6	Detailed BBN	222
10.7	Constraints on the Number of Neutrino Families	226
10.8	Problems	228

1	The Cosmic Microwave Background	229
11.1	Prelude: Transition to a Matter-Dominated Universe	229
11.2	Discovery and Basic Properties of the CMB	231
11.3	Formation of the CMB	233
11.4	CMB Anisotropies	235
11.5	The Monopole and Dipole Terms	236
11.5.1	Small-Angle Anisotropy	237
11.6	Determination of Cosmological Parameters	238
11.7	Problems	244
2	Inflation	245
12.1	The Horizon Problem	246
12.2	The Flatness Problem	246
12.3	The Monopole Problem	248
12.4	How Inflation Works	251
12.5	Mechanisms for Inflation	253
12.6	Solution to the Flatness Problem	256
12.7	Solution to the Horizon Problem	258
12.8	Solution to the Monopole Problem	259
12.9	Inflation and the Growth of Structure	260
12.10	Outlook on Inflation	262
12.11	Problems	264
3	Dark Matter	265
13.1	Large-Scale Structure of the Universe	265
13.2	Motivation for Dark Matter	266
13.2.1	Dark Stars	269
13.2.2	Neutrinos as Dark Matter	272
13.2.3	Weakly Interacting Massive Particles (WIMPs)	275
13.2.4	Axions	278
13.2.5	The Rôle of the Vacuum Energy Density	279
13.2.6	Galaxy Formation	281
13.2.7	Resumé on Dark Matter	283
13.3	Problems	285
4	Astrobiology	287
14.1	Problems	290
5	Outlook	293
15.1	Problems	297
6	Glossary	299
7	Solutions	337

A	Mathematical Appendix	381
A.1	Selected Formulae	381
A.2	Mathematics for Angular Variations of the CMB	385
B	Results from Statistical Physics: Thermodynamics of the Early Universe ...	389
B.1	Statistical Mechanics Review	390
B.2	Number and Energy Densities	396
B.3	Equations of State	398
C	Definition of Equatorial and Galactic Coordinates	401
	Important Constants for Astroparticle Physics	403
	References	405
	Further Reading	407
	Photo Credits	412
	Index	415