

*The Mystery
of the Missing
Antimatter*

Helen R. Quinn and Yossi Nir

ILLUSTRATIONS BY
RUTU MODAN

Princeton University Press

Princeton & Oxford

CONTENTS

ACKNOWLEDGMENTS xi

1. Prelude: The Mystery of the Missing Antimatter 1
2. Constant Physics in an Evolving Universe 7
 - Universal Laws* 7
 - Hubble and the Expanding Universe* 8
 - Red-shifts: Evidence for an Expanding Universe* 12
 - Numbers Large and Small* 17
 - What Do We Mean by "Universe"?* 19
3. As the Universe Expands 21
 - Running the Clock Forward: Radiation* 21
 - Running the Clock Forward: Dark Matter* 26
 - Running the Clock Forward: Light Nuclei* 29
 - Running the Clock Forward: Matter and Antimatter* 32
4. What Is Antimatter? 36
 - What Is Matter?* 36
 - Dirac Introduces Antimatter* 42
 - Experiments Confirm That Antimatter Exists* 45
 - Radioactive Decays of Nuclei* 48
5. Enter Neutrinos 51
 - Pauli: The Beta Decay Puzzle* 51
 - Fermi: The Theory of Neutrinos Develops* 53
 - Cowan and Reines: Neutrinos Detected* 55

6. Mesons 57
 - Yukawa and the Pi-Meson* 57
 - Strange Mesons, Strange Quantum Concepts* 61
7. Through the Looking Glass 63
 - What Physicists Mean by the Term Symmetry* 63
 - A Gedanken Experiment* 64
 - The Actual Experiment* 67
8. Through the Looking Antiglass 73
 - Another Gedanken Experiment* 73
 - Cronin and Fitch: Matter and Antimatter Do Not Follow the Same Laws* 75
9. The Survival of Matter 80
 - Pauli's Other Letter: Initial Conditions on the Universe* 80
 - Sakharov: The Conditions Needed to Develop an Imbalance* 84
 - Cosmology with Sakharov's Conditions Met: Baryogenesis* 88
10. Enter Quarks 91
 - Quarks* 91
 - Why Don't We See the Quarks?* 96
 - What about Dark Matter?* 100
 - The Missing Charm, the Surprising Tau* 101
 - The Standard Model: Particles and Interactions* 107
11. Energy Rules 111
 - Stored Energy, Forces, and Energy Conservation* 111
 - Force Fields Permeating Space* 114
 - Field Theory and the Energy Function* 116
12. Symmetry Rules 121
 - Symmetries as Answers to the Question "Why?"* 121
 - Symmetries and Conservation Laws* 123
 - Space-Time Symmetries* 124
 - Gauge Symmetries* 126
 - Discrete Symmetries* 128
 - Baryon and Lepton Number Conservation?* 130

13. Standard Model Gauge Symmetries 132
 - The Symmetry behind the Electromagnetic Interaction* 132
 - The Symmetry behind the Strong Interaction* 134
 - The Symmetry behind the Weak Interaction* 137
14. A Missing Piece 140
 - The Puzzle of Particle Masses* 140
 - How Do We Describe Nothing?* 146
 - At Last, CP Violated in the Standard Model* 153
15. It Still Doesn't Work! 159
 - Running the Clock Forward: The Standard Model* 159
 - Now What?* 163
16. Tools of the Trade 168
 - Accelerators* 168
 - Detectors* 172
 - Data Handling and Analysis* 177
 - How Projects Develop* 178
17. Searching for Clues 180
 - Where Are We Now?* 180
 - Testing the Standard Model in B-Meson Decays* 182
 - Oddone: How to Build B Factories?* 184
 - Running the B Factories: The First Test* 190
18. Speculations 194
 - Why Are We Never Satisfied?* 194
 - Grand Unified Theories* 195
 - Supersymmetry* 201
 - Way beyond the Standard Model* 204
19. Neutrino Surprises 206
 - Davis, Bahcall, Koshiba: Solar Neutrinos* 206
 - Quantum Neutrino Properties* 214
20. Following the New Clues 222
 - Some Things We Know* 222
 - Some Things We Speculate About* 225
 - Fitting It All Together* 227
21. Finale 231

Appendix: A Timeline of Particle Physics and Cosmology 233

- Perspective* 233
- Relevant Nineteenth-Century Developments* 234
- 1900–1930: Development of Quantum Ideas, Beginnings of Scientific Cosmology* 238
- 1930–1950: New Particles, New Ideas* 245
- 1930–1960s: The Advent of Accelerator Experiments—The Particle Explosion; Implications of Expanding Universe Explored* 249
- 1964–1973: Formulation of the Modern View of Particles and the Universe* 256
- Two Standard Models Emerge—Particles and Cosmology* 263

INDEX 273