

CONTENTS

Chapter 1

CHIRAL SYMMETRY RESTORATION AND DILEPTONS IN RELATIVISTIC HEAVY-ION COLLISIONS

R. Rapp and J. Wambach

| | |
|-----------------------------------------------------------------------------|----|
| 1. Introduction | 1 |
| 2. “Strong QCD” and Vector Mesons | 11 |
| 2.1. Symmetries and Anomalies of QCD | 13 |
| 2.2. Vacuum Condensates | 15 |
| 2.3. In-Medium Condensates via Low-Density Expansions | 18 |
| 2.4. Lattice Results | 22 |
| 2.5. Dilepton Production and Vector Mesons | 30 |
| 2.6. Vector-Axialvector Mixing | 32 |
| 2.7. QCD Sum Rules | 39 |
| 2.8. Chiral Reduction Formalism | 45 |
| 3. Modeling Vector Mesons in the Medium | 49 |
| 3.1. Effective Meson Lagrangians: Impact of Finite Temperature | 50 |
| 3.1.1. Gauged Linear σ -Model + VDM | 50 |
| 3.1.2. Massive Yang-Mills Approach | 54 |
| 3.1.3. Hidden Local Symmetry | 56 |
| 3.1.4. Phenomenological Meson Lagrangians | 62 |

| | | |
|--------|---------------------------------------------------------------------------------------|-----|
| 3.2. | Finite Baryon Density | 77 |
| 3.2.1. | Mean-Field Approach: Brown-Rho Scaling | 77 |
| 3.2.2. | Pion Cloud Modifications | 81 |
| 3.2.3. | Direct ρ -Nucleon Resonances | 94 |
| 3.2.4. | Dispersive Approaches at High Energies | 97 |
| 3.2.5. | Finite Temperature Effects in Baryonic Matter | 99 |
| 4. | Analysis of Dilepton Spectra: Constraints, Predictions, and Implications | 101 |
| 4.1. | Constraints on Hadronic Dilepton Production | 104 |
| 4.1.1. | Decay Widths and Hadronic Scattering Data | 105 |
| 4.1.2. | Photoabsorption Spectra | 109 |
| 4.2. | Dilepton Rates in Hot and Dense Matter | 117 |
| 4.2.1. | Comparison of Hadronic Approaches | 117 |
| 4.2.2. | Beyond Conventional Scenarios for Dilepton Enhancement | 125 |
| 4.2.3. | Quark-Hadron Duality | 131 |
| 4.3. | Photon Production Rates | 137 |
| 4.4. | Space-Time Evolution of Heavy-Ion Collisions | 138 |
| 4.4.1. | Hydrodynamical Approach | 139 |
| 4.4.2. | Transport Simulations | 142 |
| 4.4.3. | Thermal Fireball Expansion | 146 |
| 4.5. | Dilepton Spectra at BEVALAC/SIS Energies | 149 |
| 4.6. | Dilepton Spectra at CERN-SPS Energies | 155 |
| 4.6.1. | Decays after Freezeout: Hadronic Cocktail versus Experiment | 156 |
| 4.6.2. | Free $\pi^+\pi^-$ Annihilation in the Hadronic Fireball | 160 |
| 4.6.3. | Medium Effects I: Invariant Mass Spectra | 163 |
| 4.6.4. | Medium Effects II: Transverse Momentum Dependencies | 172 |
| 4.6.5. | Time Dependence of In-Medium Signals | 176 |
| 4.6.6. | Intermediate-Mass Spectra | 179 |

| | |
|-----------------------------------------|-----|
| 4.7. Direct Photon Spectra | 184 |
| 4.8. Theoretical Implications | 187 |
| 5. Conclusions | 193 |

*Chapter 2***FUNDAMENTAL SYMMETRY VIOLATION IN NUCLEI**

**H. Feshbach, M. S. Hussein, A. K. Kerman,
and O. K. Vorov**

| | |
|-------------------------------------------------------------------------------------------------------|-----|
| 1. Introduction | 208 |
| 2. Summary of the Experimental Results from Triple Collaboration | 210 |
| 3. Symmetry Violation within Reaction Theory | 218 |
| 4. Parity Nonconservation (PNC) in the Compound Nucleus | 222 |
| 5. The Sign Correlation Problem and the Role of $2p - 1h$ Doorway States | 224 |
| 6. Optical Model Description of PNC | 230 |
| 6.1. Optical Model Calculation of the Longitudinal Asymmetry | 237 |
| 6.2. Optical Model Analysis of the TRIPLE Data | 240 |
| 6.3. Optical Model Calculation of Spin Polarization and Rotation | 245 |
| 7. Parity Violation in Exotic Nuclei | 248 |
| 7.1. Proton and Neutron Weak Potential Strengths | 249 |
| 7.2. Halo Structure Effects on the PNC Mixing | 250 |
| 7.3. Halo Model and Evaluation of the PNC Mixing in the Ground State of ^{11}Be | 252 |
| 8. Time Reversal Symmetry Breaking | 260 |
| 9. Conclusions and Discussion | 267 |
| References | 271 |

*Chapter 3***NUCLEON-NUCLEUS SCATTERING: A MICROSCOPIC
NONRELATIVISTIC APPROACH****K. Amos, P. J. Dortmans, H. V. von Geramb,
S. Karataglidis, and J. Raynal**

| | |
|---------------------------------------------------------------------|-----|
| 1. Introduction | 276 |
| 2. Formal Theory of the Nucleon–Nucleus Optical Potential | 282 |
| 3. Momentum Space Optical Models | 285 |
| 3.1. The Full-Folding t Matrix Approach | 286 |
| 3.2. The Full Folding g Matrix Approach | 290 |
| 3.3. Results of Calculations | 294 |
| 4. Coordinate Space Optical Model | 301 |
| 4.1. The Folding Model of the Optical Potential | 302 |
| 4.2. The Helicity Formalisms | 304 |
| 4.3. Multipole Expansion of the Effective Interaction | 307 |
| 4.4. Particle-Hole Matrix Elements | 317 |
| 4.5. The Distorted Waves | 320 |
| 4.6. Amplitudes, Cross Sections and Observables | 323 |
| 5. The Two-Nucleon t Matrices | 328 |
| 5.1. The NN Interactions | 328 |
| 5.2. The Free NN t Matrices | 331 |
| 5.2.1. The Partial Wave t Matrices | 333 |
| 5.3. Solution of the Lippmann-Schwinger Equation | 335 |
| 5.3.1. Phase Shifts and Deuteron Properties | 335 |
| 5.3.2. Off-Energy-Shell t Matrices | 340 |
| 5.4. Quantum Inversion and the NN t Matrix | 348 |
| 5.4.1. Case Studies | 350 |
| 6. Nuclear Matter and NN g Matrices | 353 |
| 6.1. Nuclear Matter g Matrices | 354 |
| 6.2. g Matrices from Realistic Interactions | 358 |
| 7. The Effective NN Interaction | 366 |
| 7.1. Coordinate Space Representations | 366 |
| 7.2. The Parameterisation Scheme | 367 |

| | | |
|---------|-----------------------------------------------------------------------------------------------|-----|
| 7.3. | Effective g Matrices in Coordinate Space | 369 |
| 7.3.1. | Optimal Effective g Matrices | 372 |
| 7.3.2. | Integral and Moments of the Effective Interaction | 373 |
| 7.3.3. | Radial Variations of the Effective Interactions | 377 |
| 8. | Nuclear Structure | 380 |
| 8.1. | The Shell Model | 381 |
| 8.2. | Projected HF Theory and the PHM Model | 382 |
| 8.3. | Matrix Elements of Nuclear Structure Observables | 386 |
| 8.4. | Spectra and Properties from the Models | 387 |
| 8.4.1. | Helium Isotopes | 388 |
| 8.4.2. | Lithium Isotopes | 391 |
| 8.4.3. | The Spectrum of ^{12}C | 398 |
| 8.4.4. | The Spectrum of ^{14}N | 399 |
| 8.4.5. | The Spectrum of ^{16}O | 401 |
| 9. | Electron Scattering: Operators and Observables | 403 |
| 9.1. | Introduction | 403 |
| 9.2. | Form Factors | 403 |
| 9.2.1. | Alternative Forms of the Operator \hat{T}_{JM}^{el} | 405 |
| 9.2.2. | One-Body Operators | 407 |
| 9.3. | Results | 411 |
| 9.3.1. | $E2$ Form Factors with sd -Shell Nuclei | 411 |
| 9.3.2. | Few-Body Systems: $^{3,4}\text{He}$ | 416 |
| 9.3.3. | ^6Li and ^7Li | 419 |
| 9.3.4. | ^{12}C | 428 |
| 10. | Applications of the Coordinate Space Optical Model | 437 |
| 10.1. | Energy and Mass Variations | 438 |
| 10.1.1. | The Mass Variation with 65 and 200 MeV Protons | 439 |
| 10.1.2. | Variation with Single Particle Wave Functions | 443 |
| 10.1.3. | Results for 40 MeV Proton Scattering | 445 |
| 10.2. | Elastic Scattering from $^{3,4}\text{He}$, $^{6,7}\text{Li}$, and ^{12}C | 449 |
| 10.2.1. | Proton Scattering from $^{3,4}\text{He}$ | 449 |
| 10.2.2. | Proton Scattering from $^{6,7}\text{Li}$ | 453 |
| 10.2.3. | Scattering from ^{12}C | 455 |
| 10.3. | Scattering of $^{6,8}\text{He}$ and $^{9,11}\text{Li}$ from Hydrogen | 460 |

| | |
|------------------------------------------------------------------------------------------|-----|
| 11. Equivalent Local Potentials | 465 |
| 11.1. The Basic Problem and Solutions | 466 |
| 11.2. Local Equivalent Partial Wave Potentials | 472 |
| 11.3. Inverse Scattering | 483 |
| 11.3.1. The WKB Method | 486 |
| 11.3.2. Lipperheide-Fiedeldey Methods | 491 |
| 11.3.3. Newton-Sabatier Methods | 495 |
| 12. Inelastic Scattering | 500 |
| 12.1. Scattering from ^{12}C | 501 |
| 12.1.1. Scattering to Low Excitation States in ^{12}C | 501 |
| 12.1.2. Variations with Energy | 508 |
| 12.1.3. Isovector Excitations with (p, p') and (p, n) from ^{12}C | 510 |
| 12.1.4. Inelastic Scattering and Specification of States in ^{12}C | 513 |
| 12.2. Inelastic Scattering and $^{6,7}\text{Li}$ | 518 |
| 12.3. Scattering of Radioactive Beams from Hydrogen | 523 |
| 12.3.1. The Scattering of ^{11}Li | 523 |
| 12.3.2. The Scattering of ^6He | 526 |
| Appendix. Projection Operators and HF State Normalizations and Overlaps | 527 |
| A.1. The HF State Normalization | 528 |
| A.2. The $A-1$ Nucleon State Overlaps | 529 |
| References | 529 |
| <i>Index</i> | 537 |