# Table of Contents


**1 Hors d'œuvre** ..... 1
1.1 Fundamental Constituents of Matter ..... 1
1.2 Fundamental Interactions ..... 2
1.3 Symmetries and Conservation Laws ..... 4
1.4 Experiments ..... 5
1.5 Units ..... 6

**Part I Analysis: The Building Blocks of Matter**

**2 Global Properties of Nuclei** ..... 11
2.1 The Atom and its Constituents ..... 11
2.2 Nuclides ..... 13
2.3 Parametrisation of Binding Energies ..... 18
2.4 Charge Independence of the Nuclear Force and Isospin ..... 21
Problem ..... 23

**3 Nuclear Stability** ..... 25
3.1 $\beta$-Decay ..... 26
3.2 $\alpha$-Decay ..... 31
3.3 Nuclear Fission ..... 33
3.4 Decay of Excited Nuclear States ..... 35
Problems ..... 39

**4 Scattering** ..... 41
4.1 General Observations About Scattering Processes ..... 41
4.2 Cross Sections ..... 44
4.3 The "Golden Rule" ..... 48
4.4 Feynman Diagrams ..... 49
Problems ..... 52

**5 Geometric Shapes of Nuclei** ..... 53
5.1 Kinematics of Electron Scattering ..... 53
5.2 The Rutherford Cross-Section ..... 56
5.3 The Mott Cross-Section ..... 60

5.4 Nuclear Form Factors . . . . . 61
5.5 Inelastic Nuclear Excitations . . . . . 69
Problems . . . . . 71

**6 Elastic Scattering off Nucleons** . . . . . 73
6.1 Form Factors of the Nucleons . . . . . 73
6.2 Quasi-elastic Scattering . . . . . 78
6.3 Charge Radii of Pions and Kaons . . . . . 80
Problems . . . . . 82

**7 Deep Inelastic Scattering** . . . . . 83
7.1 Excited States of the Nucleons . . . . . 83
7.2 Structure Functions . . . . . 85
7.3 The Parton Model . . . . . 88
7.4 Interpretation of Structure Functions in the Parton Model . . . 91
Problems . . . . . 94

**8 Quarks, Gluons, and the Strong Interaction** . . . . . 97
8.1 The Quark Structure of Nucleons . . . . . 97
8.2 Quarks in Hadrons . . . . . 102
8.3 The Quark–Gluon Interaction . . . . . 103
8.4 Scaling Violations of the Structure Functions . . . . . 107
Problem . . . . . 111

**9 Particle Production in $e^+e^-$ Collisions** . . . . . 113
9.1 Lepton Pair Production . . . . . 114
9.2 Resonances . . . . . 118
9.3 Non-resonant Hadron Production . . . . . 123
9.4 Gluon Emission . . . . . 125
Problems . . . . . 126

**10 Phenomenology of the Weak Interaction** . . . . . 127
10.1 The Lepton Families . . . . . 128
10.2 The Types of Weak Interactions . . . . . 132
10.3 Coupling Strength of the Charged Current . . . . . 134
10.4 The Quark Families . . . . . 138
10.5 Parity Violation . . . . . 142
10.6 Deep Inelastic Neutrino Scattering . . . . . 145
Problems . . . . . 147

**11 Exchange Bosons of the Weak Interaction** . . . . . 149
11.1 Real W and Z Bosons . . . . . 149
11.2 Electroweak Unification . . . . . 154
Problem . . . . . 161

**12 The Standard Model** . . . . . 163

## Part II Synthesis: Composite Systems

**13 Quarkonia** ... 169
13.1 The Hydrogen Atom and Positronium Analogues ... 169
13.2 Charmonium ... 172
13.3 Quark–Antiquark Potential ... 175
13.4 The Chromomagnetic Interaction ... 178
13.5 Bottonium and Toponium ... 179
13.6 The Decay Channels of Heavy Quarkonia ... 181
13.7 Decay Widths as a Test of QCD ... 183
Problems ... 185

**14 Mesons Made from Light Quarks** ... 187
14.1 Mesonic Multiplets ... 187
14.2 Meson Masses ... 191
14.3 Decay Channels ... 193
14.4 Neutral Kaon Decay ... 195
Problems ... 197

**15 The Baryons** ... 199
15.1 The Production and Detection of Baryons ... 199
15.2 Baryon Multiplets ... 205
15.3 Baryon Masses ... 208
15.4 Magnetic Moments ... 211
15.5 Semileptonic Baryon Decays ... 215
15.6 How Good is the Constituent Quark Concept? ... 223
Problems ... 224

**16 The Nuclear Force** ... 227
16.1 Nucleon–Nucleon Scattering ... 228
16.2 The Deuteron ... 232
16.3 Nature of the Nuclear Force ... 235
Problems ... 241

**17 The Structure of Nuclei** ... 243
17.1 The Fermi Gas Model ... 243
17.2 Hypernuclei ... 248
17.3 The Shell Model ... 251
17.4 Deformed Nuclei ... 259
17.5 Spectroscopy Through Nuclear Reactions ... 262
17.6 $\beta$-Decay of the Nucleus ... 269
17.7 Double $\beta$-decay ... 277
Problems ... 281

**18 Collective Nuclear Excitations** . . . . . 283
18.1 Electromagnetic Transitions . . . . . 284
18.2 Dipole Oscillations . . . . . 287
18.3 Shape Oscillations . . . . . 295
18.4 Rotation States . . . . . 298
Problems . . . . . 307

**19 Nuclear Thermodynamics** . . . . . 309
19.1 Thermodynamical Description of Nuclei . . . . . 310
19.2 Compound Nuclei and Quantum Chaos . . . . . 312
19.3 The Phases of Nuclear Matter . . . . . 315
19.4 Particle Physics and Thermodynamics in the Early Universe . 320
19.5 Stellar Evolution and Element Synthesis . . . . . 327
Problems . . . . . 333

**20 Many-Body Systems in the Strong Interaction** . . . . . 335

**A Appendix** . . . . . 339
A.1 Accelerators . . . . . 339
A.2 Detectors . . . . . 346
A.3 Combining Angular Momenta . . . . . 356
A.4 Physical Constants . . . . . 358

**Solutions to the Problems** . . . . . 359

**References** . . . . . 383

**Index** . . . . . 391