

---

# Contents

(Sections marked \* are optional.)

Preface xvii

Chapter 1

## **The Theory of Special Relativity I: The Lorentz Transformation 1**

- 1.1 Introduction 1
- 1.2 Classical Relativity: The Galilean Transformation Equations 2
- 1.3 Electromagnetic Waves and the Luminiferous Ether 4
- 1.4 The Michelson-Morley Experiment 5
- 1.5 The Theory of Special Relativity 10
- 1.6 The Lorentz Transformations 12
  - 1.6(a) Simultaneity, Length Contraction, and Time Dilation 14
  - 1.6(b) The Twin Paradox 19
  - 1.6(c) The Velocity Transformations 21
- 1.7 Consequences of the Lorentz Transformations 22
  - 1.7(a) The Relativistic Doppler Effect 22
  - 1.7(b) Experimental Evidence of Relativistic Kinematics 24
- 1.8 The Relativistic Expressions in the Classical Limit 25

**SUMMARY 26**

**BIBLIOGRAPHY 27**

**PROBLEMS 27**

Chapter 2

## **The Theory of Special Relativity: Relativistic Dynamics 30**

- 2.1 Introduction 30
- 2.2 Relativistic Momentum 31
- 2.3 Energy 34
- 2.4 Relativistic Invariants 38
- 2.5 Force and Acceleration 42

**SUMMARY 45**

**BIBLIOGRAPHY 45**

**PROBLEMS 46**

Chapter 3

**\*The General Theory of Relativity 48**

- 3.1 Introduction 48
- 3.2 The Principle of Equivalence 49
- 3.3 Gravitational Red Shift: Gravitational Time Dilation and Length Contraction 52
- 3.4 The General Theory of Relativity: Gravitation 56
- 3.5 Predictions of the General Theory of Relativity 56

**SUMMARY 62**

**BIBLIOGRAPHY 62**

**PROBLEMS 63**

Chapter 4

**Roots of the Quantum Theory 64**

- 4.1 Introduction 64
- 4.2 Blackbody Radiation 65
  - 4.2(a) Derivation of the Planck Distribution Law 67
- 4.3 Specific Heat 72
  - 4.3(a) Specific Heat of Crystals 72
  - 4.3(b) Specific Heat of Gases 76
- 4.4 The Photoelectric Effect 77
- 4.5 X Rays 80
- 4.6 Compton Scattering 84

**SUMMARY 87**

**BIBLIOGRAPHY 88**

**PROBLEMS 88**

Chapter 5

**The Bohr-Rutherford Nuclear Atom 90**

- 5.1 Charge and Mass of an Electron 90
- 5.2 Scattering Cross Section 93
- 5.3 Coulomb (Rutherford) Scattering 95
- 5.4 The Bohr Model of the Hydrogen Atom 99
- 5.5 The Energy-Level Diagram; Emission and Absorption of Radiation 103
- 5.6 Characteristic X-Ray Lines 106
- 5.7 The Franck-Hertz Experiment 109
- 5.8 The Correspondence Principle 111

**SUMMARY 112**

**BIBLIOGRAPHY 113**

**PROBLEMS 113**

Chapter 6

**The Wave Nature of Particles 115**

- 6.1 Introduction: The de Broglie Relation 115
- 6.2 Experimental Evidence of Electron Waves 116

- 6.3 Complementarity 119
- 6.4 The Uncertainty Principle 119
- 6.5 The Wave-Particle Duality and Complementarity:  
A *Gedanken* Experiment 125

**SUMMARY 128**

**BIBLIOGRAPHY 129**

**PROBLEMS 129**

## Chapter 7

### **The Schrödinger Equation 131**

- 7.1 Introduction 131
- 7.2 The One-Dimensional Schrödinger Equation 132
- 7.3 The Time-Independent Schrödinger Equation 134
- 7.4 Interpretation of the Wave Function: Probability Density  
and Expectation Values 135
- 7.5 Wave Packets: Group and Phase Velocities 137
- 7.6 Particle in a One-Dimensional Square Well 140
  - 7.6(a) Infinite Potential Barriers 140
  - 7.6(b) Finite Potential Barriers 143
- 7.7 Parity 147
- 7.8 Tunneling 148
- 7.9 The Harmonic Oscillator 149

**SUMMARY 155**

**BIBLIOGRAPHY 156**

**PROBLEMS 156**

## Chapter 8

### **The Schrödinger Equation in Three Dimensions: The Hydrogen Atom 159**

- 8.1 Introduction 159
- 8.2 Solution of the Schrödinger Equation in Spherical  
Coordinates 160
  - 8.2(a) Probability Densities and Expectation Values 162
- 8.3 Angular Momentum in Quantum Mechanics 167
  - 8.3(a) Spatial Quantization 169
- 8.4 Degeneracy 171

**SUMMARY 172**

**BIBLIOGRAPHY 173**

**PROBLEMS 173**

## Chapter 9

### **Intrinsic Spin of the Electron 174**

- 9.1 The Zeeman Effect and Electron Spin 174
  - 9.1(a) The Zeeman Effect 174
  - 9.1(b) Electron Spin 178

- 9.2 The Pauli Exclusion Principle and the Structure of Many-Electron Atoms 179
  - 9.2(a) The Ground State of Atoms 180
  - 9.2(b) Relation between Ground-State Configuration and Chemical and Physical Properties of Atoms 182
- 9.3 Fine Structure, Spin-Orbit Coupling, and the Anomalous Zeeman Effect 185
- 9.4 The Exclusion Principle and the Symmetry Properties of Electronic Wave Functions 188
- 9.5 Masers and Lasers 191
  - 9.5(a) Spontaneous and Stimulated Emission 191
  - 9.5(b) Creating a Population Inversion: Pumping 194
  - 9.5(c) Maser and Laser Operation 195
- SUMMARY 199**
- BIBLIOGRAPHY 201**
- PROBLEMS 201**

## Chapter 10

**Molecular Structure and Molecular Spectra 203**

- 10.1 Introduction 203
- 10.2 Ionic Bonding 204
- 10.3 Covalent (Homopolar) Bonding 207
  - 10.3(a) The  $\text{H}_2^+$  Ion 208
  - 10.3(b) The  $\text{H}_2$  Molecule 210
- 10.4 Molecular Energy Levels and Molecular Spectra 212
  - 10.4(a) Rotational Energy Levels 212
  - 10.4(b) Vibrational Energy Levels 215
  - 10.4(c) Molecular Spectra 216
- SUMMARY 221**
- BIBLIOGRAPHY 222**
- PROBLEMS 223**

## Chapter 11

**Statistical Physics 224**

- 11.1 Introduction 224
- 11.2 Classical Statistical Physics 224
- 11.3 Quantum Statistical Physics 230
  - 11.3(a) Bose-Einstein and Fermi-Dirac Distributions 230
- 11.4 Liquid Helium and Bose-Einstein Condensation 235
  - 11.4(a) Bose-Einstein Condensation 240
- SUMMARY 243**
- BIBLIOGRAPHY 244**
- PROBLEMS 244**

## Chapter 12

**Solid-State Physics I: Structure of Crystalline Solids and Electron Energy Bands 246**

- 12.1 Introduction 246
  - 12.2 Cohesive Forces in Crystals 247
    - 12.2(a) Ionic Crystals 250
    - 12.2(b) Covalent Crystals 252
    - 12.2(c) Metallic Crystals 253
    - 12.2(d) Molecular Crystals 254
  - 12.3 Crystal Defects 255
    - \*12.3(a) Dislocations; Plastic Deformation and Crystal Growth 256
    - 12.3(b) Point Defects 258
      - Impurity Atoms* 258
      - Vacancies and Interstitials; Solid-State Diffusion* 259
  - 12.4 The Band Theory 260
    - 12.4(a) Bloch Functions 261
    - 12.4(b) Energy Bands and Effective Masses 262
  - 12.5 Metals, Insulators, and Semiconductors 264
  - \*12.A Appendix: The Bloch-Floquet Theorem 268
  - \*12.B Appendix: Solution of the One-Dimensional Schrödinger Equation in the Tight-Binding Approximation 269
- SUMMARY 271**  
**BIBLIOGRAPHY 272**  
**PROBLEMS 272**

## Chapter 13

**Solid-State Physics II: Electronic Properties 274**

- 13.1 Introduction 274
- 13.2 Metals 274
  - 13.2(a) The Electronic Specific Heat 274
  - 13.2(b) Electrical Conductivity 277
  - 13.2(c) Thermal Conductivity; the Wiedemann-Franz Law 281
- 13.3 Semiconductors 281
  - 13.3(a) Conductivity 284
  - 13.3(b) The Hall Effect 285
- 13.4 Semiconductor Devices 287
  - 13.4(a) *p-n* Junction Diodes 287
  - 13.4(b) Tunnel Diodes 290
  - 13.4(c) Transistors 291
    - The n-p-n Transistor* 291
    - Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET)* 292
  - 13.4(d) Optical Devices 294
    - Photovoltaic Effect* 296
    - Light-Emitting Diodes (LEDs) and Junction Lasers* 297

- 13.5 Superconductivity 298**
  - 13.5(a) Fundamental Properties of Superconductors 298
  - 13.5(b) Superconductor Technology 303
    - Josephson Junctions* 305
    - SQUID (Superconducting Quantum Interference Devices)* 306
    - Josephson Junction Logic Elements* 309

- SUMMARY 310**
- BIBLIOGRAPHY 312**
- PROBLEMS 312**

## Chapter 14

### **Nuclear Physics I: Properties of Nuclei 315**

- 14.1 Introduction 315
- 14.2 Nucleons and Nuclei 318
  - 14.2(a) Composition of Nuclei: Protons and Neutrons 318
  - 14.2(b) Size and Shape of Nuclei 320
- 14.3 Nuclear Force 324
  - 14.3(a) Origin of the Nuclear Force; the Exchange Force 326
- 14.4 Stability of Nuclei: Binding Energy 327
- 14.5 The Nuclear Shell Model 333
- \*14.6 Nuclear Magnetic Resonance (NMR) 335
  - 14.6(a) Principles of NMR 335
  - 14.6(b) Energy Absorption and Spin-Lattice Relaxation 337
  - 14.6(c) Nuclear Magnetization and the Dynamics of the Magnetization Vector 339
  - 14.6(d) Techniques for Observing NMR and Measuring  $T_1$  and  $T_2$  342
  - 14.6(e) Some Applications of NMR 346

- SUMMARY 348**
- BIBLIOGRAPHY 349**
- PROBLEMS 350**

## Chapter 15

### **Nuclear Physics II: Radioactivity and Nuclear Reactions 351**

- 15.1 Introduction 351
- 15.2 Decay Constant, Half-Life, and Activity 352
- 15.3 Radioactive Decay Processes 361
  - 15.3(a) Alpha Decay 361
  - 15.3(b) Beta Decay 363
  - 15.3(c) Gamma Rays and Nuclear Energy Levels 366
- 15.4 Mössbauer Effect 367
- 15.5 Nuclear Reactions 370
  - 15.5(a) Reaction Cross Section 372
  - 15.5(b) Nuclear Spectroscopy 373
  - 15.5(c) Compound Nucleus 376

- 15.6 Fission and Fusion 378
  - 15.6(a) Fission; Reactors 378
  - 15.6(b) Fusion 385
- \*15.7 Applications of Nuclear Physics 389
  - 15.7(a) Radioisotopes in Medicine 389
    - Diagnosis* 389
    - Radioisotopes for Therapy* 394
  - 15.7(b) Radioisotopes in Archeology 396

**SUMMARY 402**

**BIBLIOGRAPHY 404**

**PROBLEMS 404**

\*Chapter 16

**Instrumentation for Nuclear Research 407**

- 16.1 Particle Accelerators 407
  - 16.1(a) Linear Accelerators 407
  - 16.1(b) Cyclotrons and Synchrotrons 412
- 16.2 Particle Detectors 420

**SUMMARY 426**

**BIBLIOGRAPHY 426**

**PROBLEMS 427**

Chapter 17

**Elementary Particles 428**

- 17.1 Introduction 428
- 17.2 Relativistic Quantum Mechanics 429
- 17.3 Classification of Elementary Particles 431
- 17.4 Conservation Laws, Symmetry, and Selection Rules 434
- 17.5 Resonance Particles 438
- 17.6 More About Leptons 439
- 17.7 Quarks 441
- 17.8 Unified Field Theories 447

**SUMMARY 448**

**BIBLIOGRAPHY 449**

**PROBLEMS 449**

Appendix A

**The Fundamental Physical Constants 451**

Appendix B

**Table of Isotopes 453**

Appendix C

**Nobel Laureates in Physics 492**

Answers to Odd-Numbered Problems 497

Index 501