UNIVERSITY PHYSICS

VOLUME III

QUANTUM AND STATISTICAL PHYSICS

MARCELO ALONSO

Department of Scientific Affairs, Organization of American States

EDWARD J. FINN

Department of Physics, Georgetown University

Reading, Massachusetts • Menlo Park, California
Don Mills, Ontario • Wokingham, England • Amsterdam • Bonn • Sydney
Singapore • Tokyo • Madrid • Bogotá • Santiago • San Juan

CONTENTS

PART 1 QUANTUM PHYSICS

Chapter 1 The Foundations of Quantum Physics

Introduction 4 ☐ Electromagnetic radiation 4 ☐ Blackbody radiation 7 ☐ Photoelectric emission 11 ☐ Scattering of radiation by free electrons 14 ☐ Photons 18 ☐ Stationary states 22 ☐ Experimental evidence of stationary states 26 ☐ Interaction of radiation with matter 29 ☐ Particles and fields 33 ☐ Particles and wave packets 38 ☐ Heisenberg's uncertainty principle for position and momentum 39 ☐ The uncertainty relation for time and energy 43

Chapter 2 Quantum Mechanics

Introduction 53 ☐ Wave function and probability density 53 ☐ Schrödinger's equation 56 ☐ Potential step 59 ☐ Particle in a potential box 63 ☐ The harmonic oscillator 71 ☐ Energy levels and wave functions in general 75 ☐ Potential barrier penetration 80 ☐ Symmetry, wave functions, and parity 88 ☐ The time-dependent Schrödinger equation 90 ☐ Transition probabilities and selection rules 94 ☐ The formal theory of quantum mechanics 96

Chapter 3 Atoms with One Electron

Introduction 109 ☐ The hydrogen atom 109 ☐ The spectrum of hydrogen 115 ☐ Quantization of angular momentum 117 ☐ One-electron wave functions under central forces 121 ☐ The Zeeman effect 132 ☐ Electron spin 135 ☐ Addition of angular momenta 137 ☐ Spin-orbit interaction 139

Chapter 4 Atoms with Many Electrons

Introduction 150 ☐ The helium atom 150 ☐ The exclusion principle 158 ☐ Electronic structure of atoms 161 ☐ L-S coupling 164 ☐ Atoms with one or two valence electrons 171 ☐ X-ray spectra 176

Chapter 5 Molecules

Introduction 183 □ The hydrogen molecule ion 183 □ Molecular orbitals of diatomic molecules 191 □ Electronic configuration of some diatomic molecules 194 □ Polyatomic molecules 202 □ Conjugated molecules 208 □ Molecular rotations 212 □ Molecular vibrations 215 □ Electronic transitions in molecules 222 □ Conclusion 225

Chapter 6 Solids

Introduction 231 □ Types of solids 231 □ Band theory of solids 243 □ Free-electron model of a solid 246 □ Electron motion in a periodic structure 251 □ Conductors, insulators, and semiconductors 261 □ Quantum theory of electrical conductivity 268 □ Radiative transitions in solids 274

Chapter 7 Nuclear Structure

Introduction 283 □ Isotopes, isotones, and isobars 283 □ The atomic mass unit 286 □ Properties of the nucleus 286 □ Nuclear binding energy 293 □ Nuclear forces 298 □ The ground state of the deuteron 301 □ Neutron-proton scattering at low energies 303 □ The shell model 310 □ Nuclear radiative transitions 319

Chapter 8 Nuclear Processes

Introduction 329 □ Radioactive decay 329 □ Alpha decay 335 □ Beta decay 340 □ Nuclear reactions 348 □ Nuclear fission 357 □ Nuclear fusion 363 □ The origin of the elements 367

Chapter 9 Fundamental Particles

Introduction 377 □ Particle genealogy 378 □ Particles and antiparticles 379 □ Particle instability 386 □ The conservation laws 397 □ Invariance, symmetry, and conservation laws 403 □ Resonances 414 □ What is a fundamental particle? 419

PART 2 STATISTICAL PHYSICS

Chapter 10 Classical Statistical Mechanics

Introduction 434 □ Statistical equilibrium 434 □ The Maxwell-Boltzmann distribution law 436 □ Temperature 443 □ Thermal equilibrium 448 □ Application to the ideal gas 450

Chapter 11 Thermodynamics

Introduction 462 □ Conservation of energy of a system of particles 462 □ Many-particle systems: work 464 □

Many-particle systems: heat 466 □ The first law of thermodynamics 467 □ Graphical representation of processes 469 □ Special processes 473 □ Entropy and the second law of thermodynamics 475 □ Entropy and heat 480 □ Discussion of processes in terms of entropy 484

Chapter 12 Thermal Properties of Gases

Introduction 494 □ The equation of state of an ideal gas 494 □ Equation of state for real gases 497 □ Heat capacity of an ideal monatomic gas 504 □ Heat capacities of an ideal polyatomic gas 506 □ The principle of equipartition of energy 512

Chapter 13 Quantum Statistics

Introduction 519 □ Fermi-Dirac distribution law 519 □ The electron gas 522 □ Application of Fermi-Dirac statistics to electrons in metals 526 □ Bose-Einstein distribution law 528 □ The photon gas 531 □ Heat capacity of solids 536 □ The ideal gas in quantum statistics 540

Appendixes

I Relativistic mechanics 551 □ II Collisions 555 □ III Group velocity 560 □ IV Some useful integrals 562 □ V Stirling's formula 563 □ VI Lagrange's undetermined multipliers 564 □ VII The detection of particles 564

Tables 577

List of Tables 581

Answers to Odd-Numbered Problems 583

Index 589