Preface

This book has two main purposes. Firstly, we review the main theoretical methods describing decay processes induced by the strong interaction. Thus, most of the book is addressed to a broad audience within the nuclear physics community.

Secondly, this book is an attempt to clarify some fundamental aspects connected with the microscopic α-like emission theory and given parts, like Chap. 10, are addressed to nuclear theorists interested in the α-decay theory.

Nowadays experimental nuclear physics pushes its limits towards highly unstable nuclei. The theoretical description of proton-rich and neutron-rich nuclei or superheavy elements has become an important part of the modern nuclear physics. The main tool to investigate such unstable nuclei concerns radioactive decays. The family of radioactive processes triggered by the strong interaction contains various decays, namely particle (proton or neutron) emission, two-proton emission, α-decay, heavy cluster emission and binary or ternary fission. Other decay processes are induced by electromagnetic (γ-decay) or weak forces (β-decays). We will investigate only the first type of fragmentations, where the emitted fragments are left in ground or low-lying excited states. We call these decays cold emission processes. They are presently among important tools to study nuclei far from the stability line. Nuclei close to the proton drip line (proton-rich nuclei) are investigated through proton emission, while the neutron drip line region (neutron-rich nuclei) is probed by cold fission processes. Superheavy nuclei are exclusively detected by α-decay chains.

In the first part we review the phenomenological theoretical framework to investigate nuclear structure, from proton emission up to the cold fission. The main assumption is that the dynamics of emitted fragments is fully described by the potential picture. We analyze the most general method to estimate the interaction potential between the emitted fragments, given by the double folding approach. We also introduce the significant observables, characterizing emission processes from deformed nuclei, namely partial decay widths and angular distribution, in terms of the stationary coupled channels formalism and Gamow resonant states. We then extensively describe the coupled channels approach for axially symmetric and triaxial nuclei with even–even or odd-mass structure. We discuss coupled channels techniques like numerical integration, diagonalization method, analytic continuation method, distorted waves approach and two potential method. The semiclassical approach within the Cluster Model, Super Asymmetric Fission Model, Effective Liquid Drop Model and Fragmentation Theory is extensively analyzed. We also investigate the coupling between collective excitations (rotations and vibrations) of emitted fragments and the relative motion, in terms of the so called core-angular harmonics. It turns out that partial decay widths to excited states of emitted fragments are very sensitive to the relative wave function in the region of the nuclear surface, which is important especially for very unstable exotic nuclear systems.

In the second part we review mainly the α-like microscopic approaches of emission processes. Initially we discuss various methods to describe the emission of clusters from nuclei, like time dependent approach, resonating group method, Feshbach reaction theory, R-matrix approach and multi-step shell model. The description of the preformation amplitude for α-particles, as well as for heavier clusters like ^{8}Be, ^{12}C and ^{14}C is given. We apply the multi-step technique to describe α-like states above ^{208}Pb and ^{40}Ca. Pairing approach to estimate the α-particle preformation amplitude is extensively analyzed. Then we analyze the two harmonic oscillator method, describing α-clustering properties, and perform a systematic analysis of selfconsistency in α-decay theory. We give a description of the α-decay fine structure in vibrational nuclei within the Quasiparticle Random Phase Approximation. Finally, we present a short introduction into the Two Center Shell Model.

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