Part I
Phenomenological Description of Emission Processes

The importance of the interplay between the Coulomb barrier and the energy of the emitted particle (Q-value) on the α-decay was one of the most important discoveries made by Gamow [1] in the early days of the nuclear physics. It explained the exponential dependence of half lives upon the Q-value, evidenced experimentally by the Geiger–Nuttall [2, 3] law. The proposed physical picture was very simple, but contradicting the classical intuition, namely a preformed α-particle inside the nucleus penetrates quantum mechanically the repulsive Coulomb barrier.

In a phenomenological description one supposes that the dynamics of the decaying systems is fully described by a potential acting between the emitted fragments. It contains two main components, namely the nuclear attraction in the internal region, surrounded by a Coulomb repulsion. Indeed, systematic calculations of half lives for α-particle emitters have shown that experimental values are well described using an equivalent local potential [4]. The attractive depth and the radius determine the energy and wave function of the decaying state, understood as a narrow resonance [5, 6].

In this first part we will review different approaches, all of them based on the phenomenological description of emission processes, involving ground or low-lying excited states in both parent and daughter nuclei. We will introduce the main tool to describe emission processes, namely Gamow resonances. Then we will describe the experimental material in terms of the Geiger–Nuttall law for different emission processes. The double folding procedure, as the most general method to compute the inter-fragment potential, is extensively analyzed.

It turns out that half lives of α-decays or heavy cluster emission processes, predicted by these potentials, are too short and this feature is a signature that such clusters do not exist as free components on the nuclear surface. The problem of how the binary system is born from the initial nucleus concerns the microscopic description of the decay process. The so-called spectroscopic amplitude, computed by the overlap between the initial and final configurations, can explain experimentally measured half lives. We will discuss this concept in the second part, devoted to microscopic approaches.

We will introduce the general form of the wave functions describing various emission processes in terms of the so-called core-angular harmonics. Then we will analyze the methods to integrate the coupled channels system of differential equations describing emission processes, namely numerical integration, diagonalization, analytical continuation and distorted wave approach. A very important approach to compute the decay width is the semiclassical method. We will extensively analyze its application within various models in the literature.

The fine structure of the α-decay is described by considering rotational and vibrational degrees of freedom in emitted fragments, axial and triaxial symmetry of the nuclei. Then we will investigate a more general case, namely the double fine structure in the binary cold fission process.

Ternary emission processes are also reviewed. We give the general framework to describe the two proton emission in terms of hyperspherical harmonics. Then we describe the ternary fission process in terms of spheroidal harmonics.

References

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