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NUCLEI
Theory

Description of Stabilization of Octupole Deformation in Alternating-Parity Bands of Heavy Nuclei

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Abstract—The angular-momentum dependences are analyzed for parity splitting and electric dipole transitions in alternating-parity bands of heavy nuclei. It is shown that these dependences can be treated universally by employing a single parameter taken to be a critical angular momentum that characterizes the phase transition from octupole vibrations to a stable octupole deformation. Analytic expressions for parity splitting and the electric dipole transitional moment are obtained on the basis of a simple model. The results are compared with experimental data for various barium, cerium, and neodymium isotopes.

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1. INTRODUCTION

There are convincing experimental and theoretical pieces of evidence that the nuclear shape turns out to be unstable with respect to parity-violating deformations if the number of protons or neutrons in the nucleus being considered is close to some specific values (56, 88, or 134) [1]. From the microscopic point of view, the reason behind the existence of strong correlations leading to deformations of this type is that pairs of opposite-parity single-particle orbitals whose angular momenta differ by $3\hbar$ appear in the vicinity of the Fermi surface. This leads to an enhancement of the octupole–octupole component of nuclear interaction [2, 3]. Calculations within mean-field models show that, in this case, nuclei turn out to be soft with respect to octupole deformations or even assume a pear-like shape in the ground state [4–9]. An alternative explanation is given within the cluster approach. It relies on the assumption that the long-range component of nuclear interaction may lead to the formation of light clusters at the nuclear surface [10–12]. The contribution of such cluster systems leads to the appearance of a reflection-asymmetric deformation. An analysis of relevant experimental data shows that there is an interplay of the octupole-deformation strength and the alpha-decay probability [13].

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Because of deformations violating the reflection symmetry of the nuclear shape, low-lying negative-parity states connected by strong dipole and octupole transitions with the levels of the ground-state band appear in the spectra of even–even nuclei. Since the first observation of low-lying negative-parity states [14, 15], a vast amount of experimental data has been accumulated (for an overview, see [16]). The experiments that were performed recently in order to study reflection-asymmetric deformations of ^{218,220}Rn and ^{222,224}Ra in [17], ^{240}Pu in [18, 19], ^{123}Ba in [20], and ^{144,146}Ba in [21] are also worthy of note.

In nuclei featuring a strong octupole deformation, yrast negative-parity states form the 1^-, 3^-, 5^-, ... rotational bands. In the case of a static reflection-asymmetric deformation, these states, together with the members of the ground-state band, form a unified band where the angular-momentum dependence of energies of levels obeys the standard rotational law, so that negative- and positive-parity states alternate. Bands of this type are peculiar to the spectra of molecules. In the majority of even–even nuclei, negative-parity states that have low angular momenta are shifted upward, however, with respect to the positions that they would have in a unified alternating-parity band of the above molecular type. This shift, called parity splitting [22], indicates that, at low angular momenta of the nucleus, we are dealing with vibrations along the reflection-asymmetry degree of freedom rather than with a static deformation. This phenomenon could be viewed as an example of a quantum phase transition in excited states [23, 24].

The probabilities for dipole transitions between negative-parity states and members of the ground-state band are also sensitive to the strength of the