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Letter Editors' Suggestion

Microscopic aspects of γ softness in atomic nuclei

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The microscopic origin of the γ softness (fluctuations in the triaxiality parameter γ of the nuclear shape) observed in atomic nuclei is studied in the framework of the triaxial projected shell model approach, which is based on a multiquasiparticle configuration space generated from a deformed mean field. It is demonstrated that the coupling to quasiparticle excitations drives the system from a γ-rigid to a γ-soft pattern. As an illustrative example for a γ-soft nucleus, a detailed study has been performed for the ^{104}Ru nucleus. The experimental energies and a large sample of measured $E2$ matrix elements available for this nucleus are reproduced quite accurately. The shape invariant analysis of the calculated $E2$ matrix elements elucidates the γ-soft nature of ^{104}Ru.

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The emergence of collective phenomena from microscopic degrees of freedom is one of the challenging problems in quantum many-body physics. The collective features observed in condensed matter, atomic, molecular, nuclear, and other systems are generally described using macroscopic approaches. In the case of atomic nuclei, the concept of a leptodermic droplet is employed and is the basis of the collective model introduced by Bohr and Mottelson [1]. This model parametrizes the spatial deformation of the nuclear density distribution in terms of a multipole expansion. For the interpretation of the low-energy properties, it is often sufficient to consider only the quadrupole terms in the multipole expansion, which are expressed in terms of the β- and γ-shape variables. These parameters are considered as "collective" dynamical variables, the motions of which are described by the Bohr Hamiltonian [1,2]. The terminology of "rigid" and "soft" shapes is based on its quantum eigenstates: rigid shape signifies small fluctuations around the equilibrium value and soft shape implies large fluctuations. As an alternative to the geometric Bohr Hamiltonian, the algebraic interacting boson method (IBM) [3,4] accounts for the collective quadrupole degrees of freedom in the framework of a closed Lie algebra of boson operators with "rigid" and "soft" shapes defined in terms of group theoretical limits [5,6].

The nucleons are in the ballistic regime, i.e., they travel quasifree inside the nuclear surface and, due to confinement, the motion is quantized. This generates the shell structure of the nucleonic states, like the shell structure of atoms, the electronic states of molecules, or the band structure of the electrons in crystals. The quantization of the nucleonic motion governs the statics and dynamics of the nuclear shape; i.e., the nucleus may be viewed as a droplet of a fermionic liquid with long-range correlations, analogous to small metal clusters, He_3 droplets, Rydberg states in large atoms, and ultracold fermionic atom gases.

A self-consistent description of the intertwined dynamics of the shape and single-particle degrees of freedom is one of the major research themes in nuclear structure physics [2]. The adiabatic time-dependent mean-field (ATDMF) approach and the generator coordinate method (GCM) [7] have become the standard approaches to describe the collective dynamics [2,8]. The advances in computer technology and the development of the new algorithms have made the spherical shell model (SSM) a viable approach to calculate the collective characteristics of the low-lying states [9–11].

In this work, we propose the triaxial projected shell model (TPSM) [12] as an alternative approach to elucidate the triaxial characteristics of atomic nuclei. In contrast to the SSM approach, the TPSM uses angular momentum projected quasiparticle configurations of a triaxial mean field that incorporates essential correlations, and the residual correlations are included through diagonalization of the Hamiltonian. This drastically reduces the numerical effort and simplifies the interpretation of the results. We think that such a novel approach may pave a way to describe other collective features in atomic nuclei, as well as in non-nuclear mesoscopic systems consisting of a few hundred particles.

To demonstrate how γ softness arises from the TPSM picture, we have chosen the ^{104}Ru nucleus as an example because a detailed Coulomb excitation (COULEX) experiment

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