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A novel projected shell model method for nuclear level density

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Nuclear level density (NLD) is a basic property of atomic nuclei and is a crucial ingredient in nuclear reaction theories. For a quantitative, microscopic description of NLD, one should solve the exact many-body eigenvalue problem, $H|\Psi\rangle = E|\Psi\rangle$, and obtain all energy levels in the Hilbert space. However, this has turned out to be an impossible task for mid-mass and heavy nuclei if the discussion is confined in the conventional shell model. One has to develop novel shell-model methods by applying modern many-body techniques.

There is overwhelmingly experimental evidence indicating that excited nuclear states are dominated by quasi-particle (qp) excitations, which form many-body configurations with broken nucleon-pairs from different orbitals. By taking these multi-qp states as building blocks for shell-model basis, we propose a novel shell-model method for calculation of NLD in deformed nuclei. The shell-model diagonalization with two-body residual interactions yields a large ensemble of eigenstates of angular momentum and parity. We demonstrate that NLD as a statistical quantity depends sensitively on structure of deformed single-particle states.

As the first example to introduce this method, we take a well-deformed rare-earth nucleus, 164Dy, for which NLD has been studied extensively by the Oslo method. By a quantitative comparison with discrete levels from spectroscopic measurements, we show that while the pronounced step-wise structure in the low-energy NLD curve can be understood as the collective excitation and nucleon-pair breaking, the exponential growth of levels in the higher-energy NLD can be described by combination of the broken-pair states, subject to the Pauli Principle. According to the nature of NLD with increasing excitation, we divide the entire NLD curve into (1) collective regime, (2) pair-breaking regime, and (3) multi-qp regime. We discuss the formation mechanism and characteristic features of NLD for the three regimes. In addition, the parity dependence and angular-momentum-dependence in NLD are discussed with a strong emphasis of the structure effect.

A shell model calculation for NLD up to the highest excitations requires heavy computational effort. The numerical effort can be greatly reduced if we just use the full set of multi-qp configurations in the shell-model space to count levels, without carrying out configuration mixing in very large matrices. Our preliminary results show that in this way, we can obtain an NLD curve qualitatively similar to realistic calculations, and can easily extend the calculation up to the neutron separation energy to compare the result with the NLD from the neutron-resonance spacing data, for arbitrarily heavy, deformed nuclei.

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