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A novel shell model for highly excited states in heavy, deformed nuclei

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There is growing demand for better understanding of highly excited nuclear states. For nuclear astrophysics and practical applications, such as reactor technology and transmutation of nuclear waste, radiative neutron capture commonly described by the Hauser-Feshbach theory requires nuclear level density (NLD) and gamma-ray strength function (gSF) as model inputs. Calculation of effective weak-process rates of beta decay and electron capture under stellar conditions involves necessarily nuclear excited states. In nuclear fission study, each primary fission fragment is treated as a compound nucleus, for which knowledge of the initial spin-distribution (SD) of excited states is crucial. All these (NLD, gSF, weak rates, SD) are structure quantities, however, exhibit strong statistical features with high excitations.

In contrast to tremendous success achieved in the theoretical study for low-excitation regions where individual levels are discussed in detail, less has been studied for highly excited states. We show that, with new breakthroughs in many-body calculations, shell-model calculations for highly excited states are possible in the Projected Shell Model (PSM) [1]. This novel shell model [2], designed for arbitrarily heavy systems, starts from a deformed mean-field solution, transforms the basis states from the intrinsic to the laboratory frame through angular–momentum-projection [3], builds the configurations in the projected space, and then performs shell-model diagonalization in the laboratory frame. The obtained states are eigenstates of spin and parity, and the well-defined wavefunctions can be used to calculate any observables.

In this presentation, we introduce algorithms of PSM for handling huge shell-model spaces, which is an impossible task for conventional shell models. Taking heavy, deformed nuclei as examples, we show how to solve the eigenvalue problem, $H|\Psi> = E|\Psi>$, to obtain microscopic NLD [4]. We discuss features found in our NLD calculation that are previously unnoticed. To demonstrate that other observables can also be obtained in the same model, gamma-ray strength functions [5], electron-capture rates [6], Gamow-Teller strengths of beta decay [7] for highly excited states are briefly discussed. We stress that both the current theory and limited experimental evidence tend to suggest that new types of ordered collective motion may emerge in regions that are normally considered chaotic.

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