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Understanding nuclear isomerism through shell model

Nuclear isomers, which are longer-lived excited states of atomic nuclei, emerge due to structural peculiarities that impede their decay processes. Advances in measurement techniques are revealing exotic isomeric properties, leading to an ample amount of data on isomeric states. This information is crucial for both fundamental research and interdisciplinary applications across industry and science. One such application, called as isomer depletion, holds potential for energy storage. A notable example is the $21/2^+$ isomeric state in ^{93}Mo, a potential candidate for the nuclear excitation by electronic capture (NEEC). However, the NEEC probabilities suffer limitations due to the lack of knowledge of the involved nuclear electro-magnetic transition rates making theoretical estimates essential. To address this, we investigate the $N = 51$ isotones from ^{93}Mo to ^{99}Cd, examining their structural evolution by using an empirically-derived shell-model interaction [1]. The neutron-proton interaction between the $g_{9/2}$ proton and $d_{5/2}$ neutron plays a key role governing the location of the $21/2^+$ isomeric state with respect to the possible $E2$ decay branch $17/2^+$ state. A detailed quantitative analysis is conducted to explore the role of involved shell model matrix elements connecting the $g_{9/2}$ proton and $d_{5/2}$ neutron. These findings are further compared with the existing interactions in large-scale shell model calculations. This analysis provides insights that may aid in identifying new candidates for the isomeric depletion across different mass regions of nuclear chart.

Since nuclear isomers exist throughout the nuclear landscape, it is valuable to depict their global features and, if any, systematics. A striking example is the $M4$, $13/2^+$ isomers in odd-mass $^{197-207}$Pb isotopes, which support nearly constant $B(M4)$ values despite corresponding gamma-energy variations from 200 keV to 1000 keV. We can understand this characteristic behavior using generalized seniority arguments [2]. These results are further supported by full-space large-scale shell-model calculations for the neutron space consisting of $0h_{9/2}$, $1f_{7/2}$, $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$ and $0i_{13/2}$ orbitals. While the shell model effectively reproduces the experimental data, interpreting the underlying physics within such huge-dimensional Hamiltonian matrices remains challenging. The generalized seniority offers a simplification to explain these $13/2^+$ isomers and their $B(M4)$ values. The calculated results are further verified analytically. Interestingly, similar $M4$ isomers also exist in neighboring odd-mass Pt, Hg and Po isotopes. Ongoing investigations aim to determine whether the generalized-seniority arguments remain valid for the $B(M4)$ values as one moves away from the semi-magic nuclei. Such results are not region-dependent, and so these arguments are also tested in Zr region. Key implications of these findings will be discussed.

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