Abstract

We present the nuclear structure theory project focussed on the large-scale, systematic, total energy calculations using a realistic phenomenological mean-field theory approach with newly adjusted parameters with parametric correlations eliminated.

Traditional methods of the mean-field theory are combined with the powerful formal methods of the applications of the group and group representation theories to illustrate symmetry properties of – as it turns out – universal octupole magic number $N = 136$ persisting at all four octupole deformations $\alpha_{3\mu=0,1,2,3}$ simultaneously. The implied shell effects generate exotic symmetry shapes at quadrupole deformation $\alpha_{20} = 0$ and octupole deformations $\alpha_{3\mu} \neq 0$, corresponding to the point groups C_{∞}, D_{2v}, T_d, and D_{3h}. These effects are predicted to take place in nuclei around Pb for $Z \geq 82$. Experimental identification criteria of these exotic symmetries are formulated and discussed in detail.

In order to study nuclear shape evolution in multidimensional spaces, an often applied description in terms of one-dimensional trajectories is considered. Based on these considerations, the method of the quasi-classical Wentzel-Kramers-Brillouin (WKB) approximation to evaluate the barrier penetration probabilities is employed. To find trajectories of maximum probabilities, the WKB method is combined with the methods of Graph Theory of applied mathematics, in particular the well known Dijkstra algorithm.

Our total potential energy calculations predict the presence of static equilibrium deformations with significant octupole components in many nuclei with proton numbers $Z = 82 - 90$, particularly strong in nuclei around $N = 136$. We estimate the dynamical (most probable) equilibrium deformations by solving the corresponding collective Schrödinger equation; a comparison is presented and discussed.

Our realistic mean-field calculations also address the issue of the coexistence between the quadrupole and octupole shapes and implied symmetries. The comparative calculations including the higher-order multipole deformations $\lambda \geq 4$ are presented and a certain impact of α_{60} is detected in heavy nuclei in the ranges of $Z \approx 98 - 110$ and $N \approx 144 - 160$. We extend our multi-dimensional calculations to the super-heavy nuclei. The predictive power of the new parametrisation of the Hamiltonian is examined and the impact of the octupole deformations is discussed. The tetrahedral (α_{32}) magic number at $N = 196$ is predicted as well as the new geometrical configurations combining quadrupole oblate shapes with octupole-α_{33}; the corresponding results are presented and discussed.

Jie Yang

23.05.2022