Enhanced moments of inertia for rotation in neutron-rich nuclei[†]

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Nuclear rotational motion emerges due to the spontaneous breaking of rotational symmetry. As stepping away from the magic numbers, the first $I^\pi = 2^+$ state becomes lower in energy: The collective mode of excitation changes its character from vibration to rotation as the deformation develops.

Recently, various spectroscopic studies have been conducted to explore unique structures in neutron-rich nuclei. The excitation energy of the 2_1^+ state, $E(2_1^+)$, is often among the first quantities accessible in experiments and systematic measurements have revealed the evolution of the shell structure. Besides the change of the shell structure associated with the onset of deformation, the $E(2_1^+)$ value may provide rich information on exotic nuclei. A significant lowering of $E(2_1^+)$, observed in a near-drip-line nucleus ^{40}Mg, could be a signal of new physics in drip-line nuclei,[1] as the theoretical calculations have predicted that the magnitude of deformation is not enhanced in ^{40}Mg compared to the Mg isotopes with fewer neutrons.[2]

There are 657 even-even nuclei with known $E(2_1^+)$. In the present study, I limit the scope by excluding the very light nuclei ($Z < 10$), for which mean-field theory is least justified. This eliminates 22 nuclei. The experimental data evaluated as $3/E(2_1^+)$ for 635 nuclei are displayed in Fig. 1 as 'Exp.' There is no collective rotation in spherical nuclei where the MoI is zero. I defined the spherical nuclei if the calculated MoI was less than 0.1 MeV^{-1}. An additional 273 nuclei have been eliminated for that reason, leaving 362 nuclei in the present analysis.

To quantitatively measure the theoretical accuracy, I compared theory and experiment, and examined the statistical properties of the quantity $R = \mathscr{J}_{\rm th}/\mathscr{J}_{\rm exp}$. Here, $\mathscr{J}_{\rm th}$ and $\mathscr{J}_{\rm exp}$ are the theoretical and experimental MoI. For the SkM* functional, the average is $\bar{R} = 1.02$. Here, the Yamagami-Shimizu-Nakatsukasa pairing functional[3] was adopted. When excluding the weakly deformed nuclei with the deformation parameter $\beta < 0.1$, $\bar{R} = 1.07$ for 332 data. Therefore, the present model overestimates the MoI by about 10%. This analysis indicates that the 2_1^+ state is mostly governed by the rotational MoI of the ground state, and the self-consistent cranking model describes the MoI surprisingly well for nuclei with a finite β value.

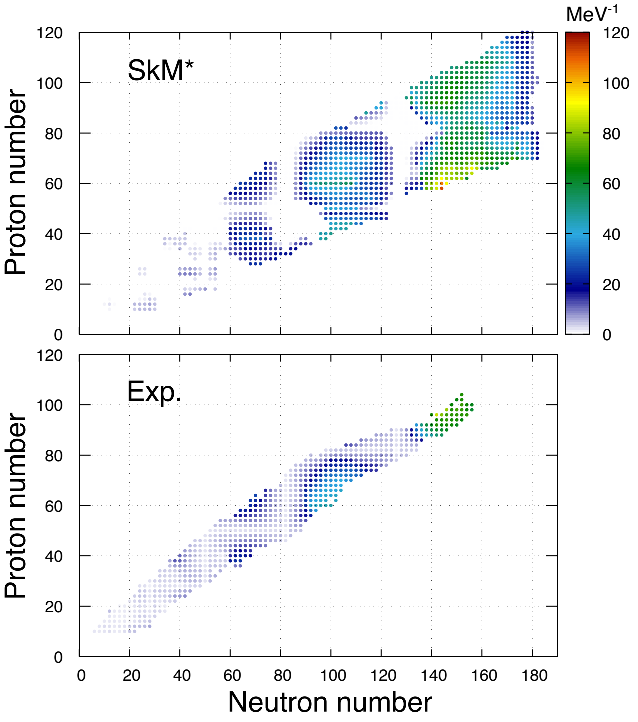

Fig. 1. Calculated moments of inertia $\mathscr{J}$ for the SkM* functional. The experimental data are taken from NNDC, which is evaluated as $3/E(2_1^+)$.

I investigate the MoI of neutron-rich nuclei, and discussed the unique features near the drip line. A striking feature observed in the result shown in Fig. 1 is that the deformation is strong in the neutron-rich lanthanide nuclei around $N = 100$ and the MoI is large accordingly. Furthermore, the MoI in nuclei near the drip line is comparable to that of heavy actinide nuclei, despite a mass number difference of about 40. The MoI in the lanthanides with $N \sim 150$ is about twice as large as that in the $N \sim 100$ region, although the deformation of protons is almost the same. Because the neutrons are spatially extended, β of neutrons and matter are both smaller than those in the $N \sim 100$ region, which is against a simple perspective for a large MoI. The density dependence of a pairing functional employed in the calculation is the origin of this unique feature near the drip line, and that weak binding plays a minor role.

References
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