Shell Gaps in the Sn Isotopes

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The exploration of nuclear shell structure is still a subject of great current interest, particularly in view of new information gathered by experiments with radioactive beams, see e.g. [1, 2]. A key feature are shell closures relative to the appearance of magic or semi-magic nuclei. A theoretical exploration of the proton shell closure in Pb isotopes was published in [3]. Here we want to present first results from a similar study for the chain of Sn isotopes.

The notion of a shell closure comes from a mean-field description where one has full insight into the single-nucleon energies ϵ_k. A shell closure is associated with a large gap in the spectrum of ϵ_k. However, these single-nucleon energies are not directly observable in experiment. A quantity which is accessible from mass systematics is the so-called two-proton shell gap

$$\delta_{2p} = E(Z+2, N) - 2E(Z, N) + E(Z-2, N) \quad . \qquad (1)$$

In case that the single-particle energies do not change much within the three isotones considered and that the change in the total binding energy comes from the variation of occupations around the Fermi surface, Koopman's theorem states that δ_{2p} represents twice the gap in the single-nucleon spectrum. This requires, however, that no dramatic rearrangements happen amongst the three nuclei involved in δ_{2p}. In the following, we will investigate the impact of such rearrangements. To that end, we employ a self-consistent mean-field description in terms of Skyrme-Hartree-Fock eventually with some correlations added.

The theoretical description is handled at several levels of refinement. We start from purely spherical calculations mean-field for all involved nuclei. This minimizes rearrangement effects and comes close to the situation assumed in Koopman's theorem. In a second step, we allow for deformations. Most nuclei will sty spherical. But the softer ones may prefer a spontaneous transition to deformed shape. Soft systems, however, are not well deformed either. The fluctuate through a whole landscape of deformations. This gives rise to collective correlation effects which we include in the third and last step of our treatment (for details see [4]).

Figure 1 shows results for the two-proton shell gap along the chain of Sn isotopes, computed with the Skyrme force SkI3 [5] at the three levels of approximation as discussed above. The spherical calculations produce a more or less constant gap with a slight trend to increase towards decreasing neutron number. This feature agrees in value and trend nicely with the spectral gap at the Fermi energy found in the single-proton spectra of the Sn isotopes. But the spherical results are far from the experimental values. The same happened in the Pb isotopes [3]. The point is that the δ_{2p} involves the $Z \pm 2$ nuclei which have no magic shell any more. Thus they are much softer and often develop some deformation. This lowers the energies

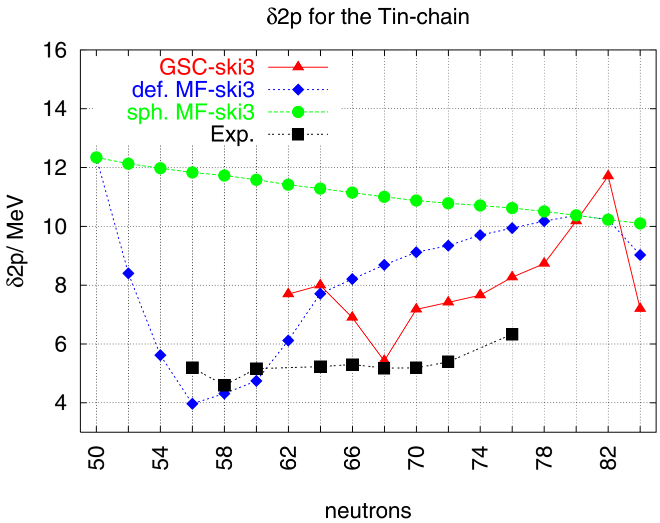

Figure 1: The two-proton shell gap δ2p as defined in eq. (1) calculated for the Skyrme interaction SkI3 at various levels of approximation: circles = purely spherical mean field, diamonds = deformed mean field, triangles = deformed mean field plus collective correlations, boxes = experimental values.

$E(Z \pm 2, N)$ as compared to their spherical values while the magic isotopes stay spherical and their $E(Z, N)$ remains unchanged. it is obvious that this rearrangement of the $Z \pm 2$ neighbors will reduce the two-proton shell gap. And that is seen nicely in figure 1. All nuclei near the magic neutron number stay spherical and the freedom to deform is not exploited. Farther away from $N = 82$, the neighbors Cd ($Z = 48$) and Te ($Z = 52$) develop deformation and we see a substantial reduction of δ_{2p} from that. Even though, the deformed results are still far from the experimental values. Finally, we invoke the collective correlations which is, in fact, the correct treatment of the soft nuclei next to Sn. This provides nicely a further push towards the experimental values. There remains, however, still some mismatch. It is not feature of this particular force SkI3. The same results is found with several other Skyrme forces and it hints at further correlation effects, yet missing.

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