How doubly-magic is the nucleus $^{78}_{28}\mathrm{Ni}_{50}$?

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Doubly-magic nuclei play an important role in nuclear structure theory as testbeds for shell model calculations. Data on neutron-rich nuclei in the regions of doubly-magic nuclei such as $^{78}_{28}\mathrm{Ni}_{50}$ and $^{132}_{50}\mathrm{Sn}_{82}$ have a decisive influence on nucleosynthesis calculations. These "longer-lived" waiting-point nuclei determine the duration of the r-process and the matter flow through the abundance maxima at the magic neutron numbers [1]. Remaining deficiencies prior to the abundance maxima in r-process calculations have been interpreted as signatures of new nuclear structure effects near the neutron drip-line, for example overestimation of the shell strength far from stability in global mass models such as FRDM and ETFSI-1. A weakening ("quenching") of spherical shells with increasing isospin, resulting in a gradual setting in of collectivity, has been predicted by recent HFB calculations, and is well established for the lower neutron-magic numbers N=20 and N=28.

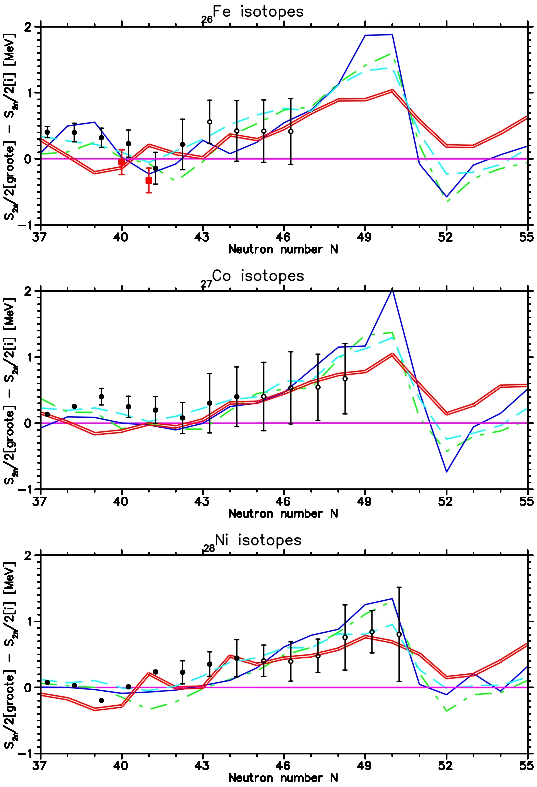

Figure 1: Deviations of experimental [black dots: 2003 mass evaluation [7], red squares: FRS/ESR measurements [8]] and theoretical S_{2n} values from the smoothly varying Groote mass formula [2] across the shell gap at N=50 are shown for $_{26}$Fe (upper part), $_{27}$Co (middle part) and $_{28}$Ni (lower part) isotopes. [Theoretical masses: Groote: magenta, FRDM: red [3], ETFSI-1: cyan [4], HFB-2: green [5], HFB-8: blue [6]]

In this context, it is of interest to determine the mutual influence of the proton and neutron magic numbers far from stability. The shell strength can be derived from the differences of the two-neutron separation energies S_{2n} prior and behind a magic neutron number. Fig. 1 displays differences between experimental and theoretical S_{2n} values relative to the smoothly varying mass formula of Groote et al. [2] for Fe, Co and Ni isotopes.

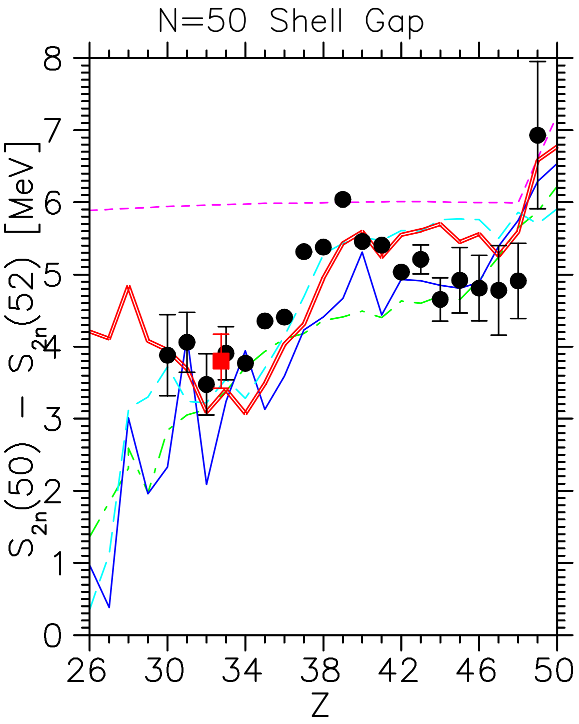

Figure 2: The N=50 shell gap as a function of Z. Experimental and extrapolated values from the 2003 mass evaluation [7] (black circles) and experimental values from direct mass measurements at ESR/FSR [red square] are compared to theoretical mass models. [Same colour coding for the mass models as in Fig. 1.]

Fig. 2 shows the N=50 shell gap over a wide Z range. Most global mass models predict a local maximum for doubly-magic ^{78}Ni. So far, below Z=30 no experimental masses have been determined, so that this prediction cannot be verified. With upgraded U-beams, direct mass measurements at the FRS-ESR of GSI will in future extend the range of experimental masses in this region to more neutron-rich isotopes.

References

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