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Exotic nuclei near ^{78}Ni in a shell model approach

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Abstract. The shell model predictions for even $^{68-76}$Ni isotopes and odd-A Cu isotopes with newly derived effective interaction for the $f_{5/2}p_{3/2}p_{1/2}g_{9/2}$ model space are presented.

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The region close to $^{78}_{28}$Ni$_{50}$ nucleus is an example of the exotic part of the nuclide chart that attracts growing interest [1,2,3,4]. The main issue is the doubly magic nature of the $^{78}_{28}$Ni$_{50}$ nucleus and properties of the effective nucleon-nucleon interaction at high isospins. Since the most important shell-model orbitals (namely $p_{3/2}$, $f_{5/2}$, $p_{1/2}$ and $g_{9/2}$) for valence neutrons in nuclei with $Z = 28$ and $N = 28$–50 (^{56}Ni-^{78}Ni) are the same as those for valence protons in nuclei with $N = 50$ and $Z = 28$–50 (^{78}Ni-^{100}Sn), the study and comparison of these two groups of nuclei helps to learn about the properties of the $T = 1$ part of the effective interaction at extreme values of isospin ($T = 11$ for ^{78}Ni, for example). Studies of the evolution of the single-particle orbitals with an increase of isospin contributes to the understanding of the properties of spin-orbital interaction, monopole terms of residual interaction and their interplay.

Experimental investigations of neutron-rich nuclei have greatly advanced the last decade providing access to many new regions of the nuclear chart. This indicates the growing need for theoretical interpretations in the framework of shell-model, for example, which, however, is lacking in well determined effective interactions for exotic regions.

Recently we have reported on the $T = 1$ part of the effective interaction for the above mentioned $pf_{5/2}g_{9/2}$ model space [5]. It was derived from a fit to experimental data for Ni isotopes from $A = 57$ to $A = 78$ and $N = 50$ isotones from ^{79}Cu to ^{100}Sn for neutrons and protons, respectively. The starting point for the fitting procedure was a realistic G-matrix interaction based on the Bonn-C NN potential together with core-polarization corrections based on a ^{56}Ni core.

The properties of neutron-rich nickel isotopes between ^{68}Ni and ^{78}Ni are of our particular interest. It is useful to look at the structure of these nuclei and compare them to

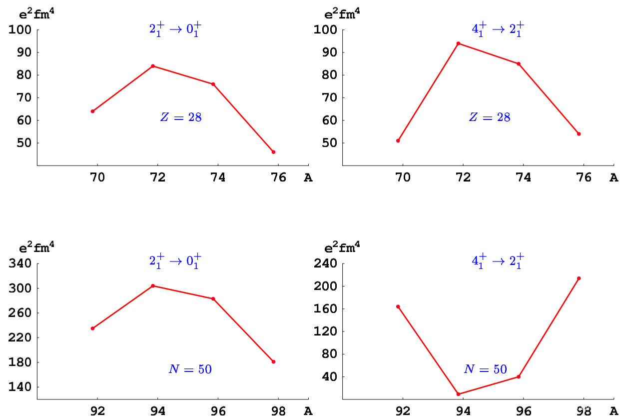

Fig. 1. Calcualted $B(E2; 2_1^+ \to 0_1^+)$ and $B(E2; 4_1^+ \to 2_1^+)$ values for $Z = 28$ isotopes with $A = 70$–76 (upper part) and $N = 50$ isotones with $A = 92$–98 (lower part).

$A = 90$–98 $N = 50$ isotones taking into account that the shell model calculations are performed in the same configurational space. Our calculations show that the nuclear structure is dominated by the $(pf_{5/2})^{12}_{0^+}(g^n_{9/2})_J$ configurations ($n = 2$–8 for A running from 70 [92] to 76 [98] for neutrons [protons]) in both cases. However, the effective two-body interaction for the $g_{9/2}$ orbital in a vicinity of ^{78}Ni is very different from that in a region close to ^{100}Sn. The neutron interaction is stronger in $J^\pi = 2^+$ and $J^\pi = 4^+$ channels that drastically changes some of the nuclear structure features for Ni-isotopes as compared to corresponding $N = 50$ valence mirror symmetry partners. First, the seniority $s = 4$ $J^\pi = 6^+$ state is pushed below the 8^+ state with $s = 2$ reducing the lifetime of the latter by three orders of magnitude in ^{72,74}Ni as compared to ^{94}Ru and ^{96}Pd, respectively [6]. Second the $4^+_{s=4}$ state

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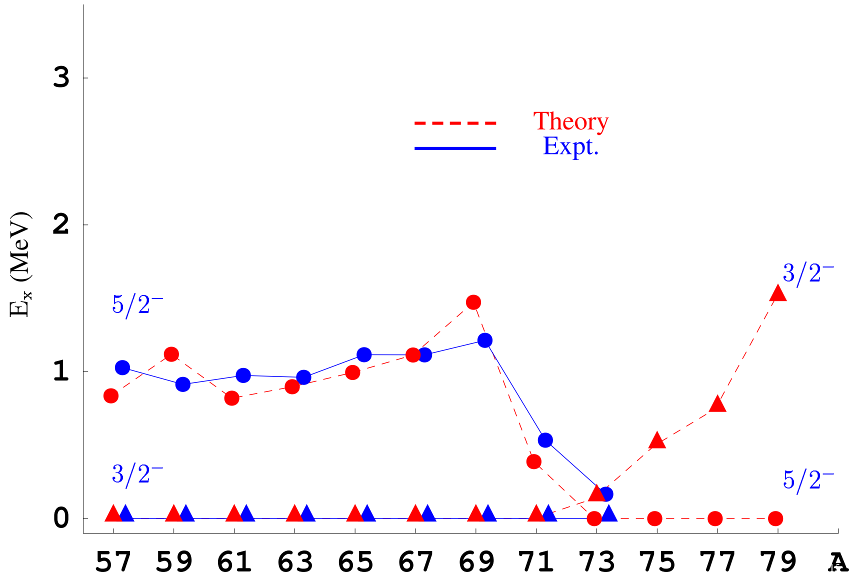

Fig. 2. Calculated and experimental excitation energies of the lowest states with $J^\pi = 3/2^-, 5/2^-$ for A-odd Cu isotopes. Experimental points are connected by the solid line and theoretical by the dashed one.

appears as the lowest 4^+ state in ^{72,74}Ni that is in contrast to ^{94}Ru and ^{96}Pd where the lowest 4^+ state has $s = 2$. This changes the character of the $E2$ strength systematic resulting in enhanced $B(E2; 4_1^+ \to 2_1^+)$ values near the middle of the $g_{9/2}$ shell (^{72,74}Ni) while reduction is appropriate for the ^{94}Ru and ^{96}Pd. This difference is illustrated by fig. 1.

This difference indicates a transition from the seniority scheme with strong pairing appropriate for the $N = 50$ isotones to a vibrational-like collective picture in the single $g_{9/2}$ orbital for neutron-rich nickel isotopes [7].

Experimental confirmation of such changes is of great interest for the understanding of the doubly-magic nature of the ^{78}Ni nucleus [8].

Proceeding towards the proton-neutron part of the effective interaction we have analyzed the odd-mass Cu isotopes. Since Cu isotopes have one proton above the assumed ^{56}Ni core their spectra is influenced only by the neutron-neutron and the proton-neutron parts of the interaction. Furthermore the odd-A Cu isotopes are sensitive only to the monopole part of the proton-neutron interaction. Therefore fitting odd-A Cu isotopes one can determine the proton-neutron monopole part of the effective interaction.

To do this we have taken the $T = 1$ proton-neutron monopole part to be identical to the neutron-neutron one. Than the $T = 0$ monopole part of the original G-matrix was modified to fit known experimental energies of the odd-A Cu isotopes and to link proton single-particle energies determined in the vicinity of ^{56}Ni with the ones in ^{79}Cu predicted with the new effective interaction for $N = 50$ isotones. Combining the monopole corrected $T = 0$ part of G-matrix and the $T = 1$ part of the newly fitted interaction we have made calculations for the unknown states in neutron-rich Cu isotopes with $A = 71$–77. Our calculations predict a near degeneracy of the $J^\pi = 3/2^-$ and $J^\pi = 5/2^-$ states in ^{73}Cu that is illustrated in fig. 2. The situation is more certain for the $A = 75, 77$ and 79 where the excited $3/2^-$ state is predicted to be well above the ground $5/2^-$ state. This is supported by recent preliminarily data for the magnetic moment of the ground state of ^{75}Cu [9] which is in good agreement with the calculated one for the $J^\pi = 5/2^-$ state.

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