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Systematic Investigation of Nucleon Knockout around ^{132}Sn

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Neutron- and proton-removal cross sections for nuclei around ^{132}Sn have been systematically measured. The measurements clearly show the effect of the N=82 closed shells. Model calculations describing all processes leading to single nucleon removal residual nuclei provide a reasonable description of the neutron removal process but clearly overestimate the proton removal ones. This overestimation of the proton removal channels could be explained as due to the presence of short-range correlated neutron-proton pairs in nuclei.

KEYWORDS: Medium-mass neutron-rich nuclei, neutron and proton removal, short-range correlations

1. Introduction

Neutron- and proton-removal processes are widely used not only to produce nuclei far from stability [1] but also to investigate the structural properties of bound [2] and unbound [3] nuclear systems. Despite its interest and apparent simplicity, a complete understanding of single-nucleon removal has not yet been achieved. Indeed, the measured proton-removal cross sections from stable [4] and neutron-rich [5, 6] medium-mass projectiles are much lower than calculated with standard reaction models.

A similar overestimation has been observed for the removal of deeply-bound nucleons in light-projectiles knockout reactions [7]. In that case, the measurements indicate a quenching of the spectroscopic factors calculated with a shell model that strongly depends on the binding energy of the removed nucleon. However, this result has become controversial because measurements of the spectroscopic factors for the same nuclei but using transfer reactions show a reduction of the spectroscopic factors but no dependence on the binding energy [8].

The over-predicted single-particle occupancies in shell model calculations are explained due to the presence of short-range correlated nucleon pairs in nuclei, produced by the tensor component of the nuclear force. Because of the large relative momentum between the two nucleons in the pair, the knockout of one of those also produces the emission of the partner, reducing the probability of single nucleon-removal remnants. The CLAS collaboration first established that in ^{12}C 20% of the nucleons form short-range correlated pairs, and most of them are neutron-proton pairs [10]. More recently, they have confirmed that this is a universal pattern also present in medium-mass and heavy stable nuclei, that by nature are neutron-rich [11].

To contribute to this discussion, in this work we have systematically measured the single neutron- and proton-removal cross sections in medium-mass nuclei around ^{132}Sn.

2. Experiment

The experiment was performed at GSI (Darmstadt) where the SIS18 synchrotron was used to accelerated beams of ^{132}Xe and ^{238}U at energies around 950A MeV. The fragmentation of ^{132}Xe [4] and the fission of ^{238}U [12], on a beryllium target, made it possible to produce medium-mass nuclei covering long isotopic chains, in particular around ^{132}Sn.

In this experiment, the zero-degree magnetic spectrometer Fragment Separator (FRS) was used as a double spectrometer. The first section provided the separation and identification of the medium-mass nuclei produced in the above mentioned fragmentation and fission reactions. A second beryllium target was installed at the intermediate image plane of the spectrometer to induce the single neutron- and proton-removal reactions. The second section of the spectrometer was then used to identify the final nuclei produced in those single nucleon-removal processes. A detailed description of the experiment and the data sorting can be found in Ref. [5].

3. Results

In this experiment we investigated 74 medium-mass nuclei although here we only report the results obtained with tin isotopes. For all of them we could determine the single neutron-removal cross sections and for some of them also the single proton-removal cross sections. In particular both processes were systematically measured around ^{132}Sn.

In Fig. 1 we report the measured single neutron-removal cross sections (solid points in the upper panel) and single proton-removal cross sections (solid points in the lower panel) for tin isotopes. In this figure we also report similar measurements previously reported in literature [13–15]. As can be seen, there is a very good agreement in the measurements done for the same nuclei in different works. Moreover, the combination of these sets of data provides a complete coverage of the single nucleon-removal cross sections from ^{104}Sn until ^{135}Sn.

The cross sections for a single-neutron removal of neutron-rich isotopes are relatively large, $\approx$ 150 mb, while the corresponding proton-removal cross sections are almost an order of magnitude smaller, $\approx$ 15 mb, confirming the previously observed quenching of these cross sections. However, both cross sections become similar for the lighter tin isotopes measured in this work. Moreover, the single neutron-removal cross sections show a clear drop for ^{134}Sn, while for the single-proton removal this drop appears for ^{133}Sn. In both cases the reduction in the cross sections can be explained by the lower binding energies and larger excitation energies of the single-nucleon removal remnants due to the close shell N=82.

For the interpretation of these inclusive measurements we ran model calculations using an advanced version of the intra-nuclear cascade model, including a realistic descriptions of the nucleon densities [16]. These calculations take into account not only the direct nucleon knockout process and the induced particle-hole excitations, but also initial and final state interactions, in particular collec-

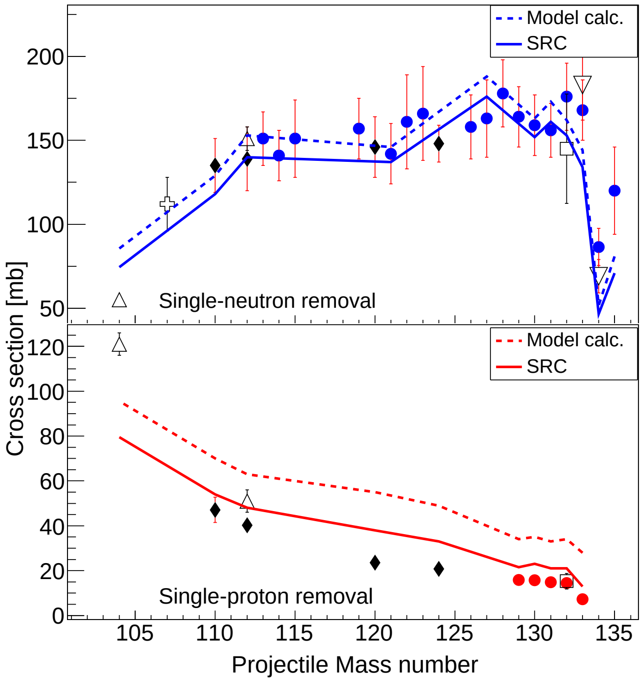

Fig. 1. Single neutron- (upper panel) and proton-removal cross sections (lower panel) for tin isotopes measured in this work (solid points), together with other measurements reported in literature [13–15]. The dashed lines represent standard calculations while the solid line corresponds to calculations where the effect of short-range correlated neutron-proton pairs is considered phenomenologically.

tive excitations contributing to the nucleon-removal channel, as the GDR and GQR, and multiple scattering of the knockout nucleons, increasing the excitation energy gained by the final remnants.

The results of the calculations are shown by the dashed lines in Fig. 1. As can be shown these calculations reproduce reasonably well the single neutron-removal cross sections, including the drop of the cross section for ^{134}Sn. This drop is explained by the higher excitation energies induced by particle-holes when the valence neutrons are above the shell gap N=82, as it is the case for the tin isotopes heavier than ^{132}Sn, and the lower binding energies of the final remnants. However, the same calculations overestimate by around 60% the single proton-removal cross sections.

According to our best knowledge, this overestimation in the single proton-removal cross sections can not be explained by the possible uncertainties in our model calculations because we reproduce reasonably well the neutron-removal cross sections, neither by the radial distributions of protons and neutrons which are calculated using to state-of-the-art models [16]. Therefore, some of the basic assumptions in our model calculations should be incomplete.

One of the possible explanations could be the limitations of the mean-field approach used in our calculations. Indeed, today we know that a non-negligible fraction of nucleons in the nuclei, $\approx 20\%$, are coupled in neutron-proton pairs by the short-range tensor interaction [10]. Moreover, this fraction seems to be universal regardless, producing a relative increase of protons in short-correlated pairs with the neutron-excess of the nuclei [11, 17]. These short-range correlated pairs could have a direct impact into the inclusive single nucleon-removal cross sections. Indeed, the knockout of one of the short-range correlated nucleons will automatically produced the emission of the partner because of their large relative momentum. Those collisions will reduce the probability of the A-1 remnants in favor of the A-2 ones.

In order to test the effect of these short-range correlated pairs in the cross sections measured in this work, we parametrized the fraction of neutrons and protons in short-range correlated pairs as a function of the neutron-excess of the nuclei obtained by the CLAS collaboration [11]. We then introduced a reduction in the calculated cross sections for the single-removal processes following this parametrization. The result is shown by the solid lines in Fig. 1.

As can be seen, the effect on the single neutron-removal cross sections is rather small but sufficient to provide a satisfactory description of the proton-removal cross sections. The reason is that because of the constant fraction of nucleons in proton-neutron pairs, ≈ 20 %, the relative number of short-range correlated neutrons in neutron-rich nuclei is relatively small, while the relative fraction of short-range correlated protons is not negligible. For example, in the case of ^{132}Sn we expect 26 nucleons forming neutron-proton pairs. This means that 13 neutrons out of 82 and 13 protons out of 50 participate in short-correlated pairs. Consequently, it is more probable to knockout a short-range correlated proton than a neutron.

4. Conclusions

74 medium-mass nuclei covering long isotopic chains were produced at the FRS(GSI) using the fragmentation of ^{132}Xe projectiles and the fission of ^{238}U projectiles at energies around 950A MeV. The cross sections of single neutron- and proton-removal processes were systematically measured, in particular around ^{132}Sn.

Advanced model calculations based on the intra-nuclear cascade model, including initial- and final-state interactions, and a shell model description of the energies and occupancies of the single-particle orbitals of the investigated nuclei, were used to interpret the measured cross sections. Single neutron-removal cross sections were described with an accuracy close to 10%. However, the same calculations overestimated the single proton-removal cross sections by more than 60%.

Finally, the impact of short-range correlated pairs in the knockout process was phenomenologically included in the model calculations. This was done assuming a universal value of 20% of nucleons forming neutron-proton short-correlated pairs and that every time a short-correlated nucleon is knockout, the partner is also emitted, reducing the probability of final single-removal residues. These new calculations provide a satisfactory description of both, single neutron- and proton-removal processes. This result suggests that short correlations in nuclei could explain the observed quenching of the proton-removal cross sections and the isospin dependence of the quenching of the spectroscopic factors obtained with knockout reactions.

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