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High precision γ spectroscopy of ^{69,71}Zn from (n,γ) reactions using EXILL

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Abstract. Measurement of γ radiation following slow neutron capture on ^{68}Zn and ^{70}Zn using very efficient germanium array EXILL was done at Institute Laue-Langevin in Grenoble. New spectroscopic information for ^{69}Zn (including doorway state) and first results for ^{71}Zn (accurate energy of β decaying isomer) were obtained. Binding energies for ^{68}Zn, ^{69}Zn and ^{71}Zn were determined with 5-to-70 times higher accuracy than presented in the literature.

1 Introduction

The neutron-rich nuclei in the vicinity of $Z = 28$ and $N = 40, 50$ shell closures are important playground for probing nuclear models. The systematic behaviour of the energies of the 2^+ excited states in this region is presented in Fig. 1. An interesting regularity, called isotonic symmetry or valence proton symmetry [1], is seen as the 2^+ energies of certain pairs of isotones have similar values. These are: Se and Fe (two protons/holes in the f orbital), Kr and Cr (four protons/holes in the f orbital), Ge and Zn isotones (protons in the $p_{3/2}$ orbital). It is also seen that the occupation of the $p_{3/2}$ orbital is already sufficient to eradicate the N=40 shell closure, which is present only in Ni isotopes. Furthermore, in a recent study [2] an onset of deformation has been found at N > 36 in Fe isotopes, corresponding to two proton holes in the $Z = 28$ shell.

The Shell Model is able to describe nuclear excitations not only in closed-shell nuclei and their immediate neighbours, but also in nuclei with larger number of valence nucleons, reproducing also collective effects there [3–6]. The reliability of such studies critically depends on a precise information concerning the structure of nuclei of interest, like the identification of all low-lying excited levels, their spins, parities and decay properties. It is well established that the neutron capture reactions serve as an excellent tool for such type of "complete" spectroscopy. With the development of very efficient arrays of γ spectrometers, the measurements of γ radiation following the neutron capture reactions offer now new, rich and complete information on nuclear structure [7].

Our recent measurements of γ radiation following slow-neutron capture on ^{68}Zn and ^{70}Zn nuclei, performed

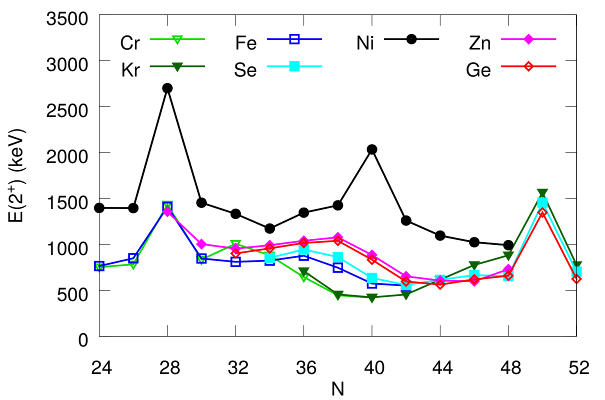

Figure 1. Systematics of energies $E(2^+)$ values for even-even nuclei with $N = 24 - 52$.

with the very efficient germanium array EXILL at ILL Grenoble provided rich, new information on ^{69}Zn and ^{71}Zn isotopes (for the latter nucleus it was the first measurement with slow neutrons). One can study here interesting effects like the onset of collectivity in the vicinity of $N = 40$ shell closure or the population of high-spin isomers. Starting from a capture level with much lower spin, they are fed through the so-called intermediate (doorway, gateway) states, which have important astrophysical and practical applications (medical radioisotopes, pumping of γ lasers).

2 Results

The first step of the data analysis was to calibrate the EXILL array. A very precise energy calibration was done basing on ^{28}Al lines. A single, second order polynomial was fitted to the data points in the entire 0-9 MeV range.

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The accuracy is of the order of 20 eV and the systematic error is about 15 eV (this estimate is based on the comparison of calculated and tabulated value of neutron binding energy for ^{28}Al). Furthermore, the efficiency calibration in a range from 30 to 8000 keV was performed.

Using these precise calibrations and high statistics coincidence data (10^{10} triggerless single (γ, time) events, 10^9 $\gamma\gamma$ coincidence events and $2{\cdot}10^8$ $\gamma\gamma\gamma$ coincidences) we have obtained significantly extended and more precise information on ^{69}Zn and ^{71}Zn nuclei. A partial level scheme of ^{69}Zn is shown in Fig. 2. Angular correlations and polarization measurements resulted in unique spin and parity assignments. The 872.5-keV level has spin and parity $5/2^+$ due to observation of the 5609.7-keV feeding – primary transition. It decays solely to the $9/2^+$ isomer and is fed from the 1178.5-keV, newly observed level, showing features of a doorway state for the isomer.

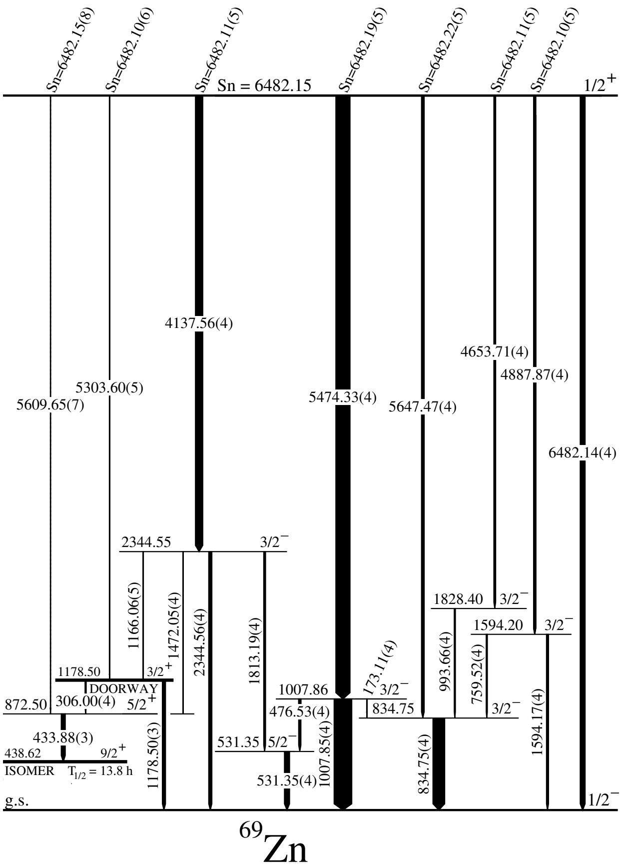

Figure 2. A fragment of ^{69}Zn level scheme.

In our spectra we could identify at least 90 primary transitions in ^{69}Zn (to be compared with 13 primary transitions reported in the literature). Using such cascades, and the precise energy calibration we have determined neutron binding energies of ^{68,69,71}Zn isotopes observed in our data with much higher accuracy than reported before, as shown in Table 1.

With these accurate S_n values, excitation energies of the $9/2^+$ isomers in ^{69}Zn and ^{71}Zn were determined very precisely, as shown in Table 2. The energy of 438.62(5) keV for ^{69}Zn agrees well with the literature value of 438.638(18) keV, justifying this method.

Table 1. Comparison of neutron separation energies S_n reported in this work with literature values [8].

Nucleus	Literature	This work
$S_n(^{68}$Zn)	10198.10(19) keV	10198.32(4) keV
$S_n(^{69}$Zn)	6482.07(16) keV	6482.15(3) keV
$S_n(^{71}$Zn)	5835(3) keV	5832.60(4) keV

Table 2. Comparison of energy of $9/2^+$ isomeric state reported in this work with literature values. Energies are given in keV.

Nucleus	Literature	This work	Decay mode
^{69}Zn	438.636(18) [9]	438.62(5)	99.967% IT
^{71}Zn	157.7(13) [10]	155.62(6)	100% beta

Systematics of $5/2^+$ states in odd-A Zn isotopes, compared in Fig. 3 to 2^+ energies in the respective Zn cores suggest collective character of the $5/2^+$ excitations, built on top of the $9/2^+$ isomers. The halflife of the $5/2^+$ level in ^{71}Zn was measured in this work to be about 40 ns. This preliminary value translates to B(E2) of about 19 W.u., which is similar to the collectivity observed in the core ^{68,70}Zn nuclei.

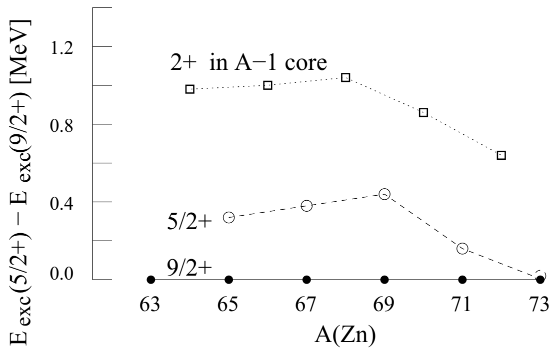

Figure 3. Systematics of $5/2^+$ states in odd-A Zn isotopes.

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