GAMMA SPECTROSCOPY OF LOW-ENERGY ISOMERIC STATES IN NEUTRON-RICH NUCLEI: ^{75}Cu*

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We present the results of an experiment in which the structure of neutron-rich nuclei located in the vicinity of $N = 40$ was studied. The importance of our results comes from the fact that knowing the behaviour of the neutron $g_{9/2}$ orbital with increasing neutron number is one of the key points in defining the structure of these nuclei at low excitation energy. Preliminary results on the isomers of ^{75}Cu will be presented together with tentative spin and parity assignments.

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1. Introduction

Nuclear structure of nuclei near the neutron-rich region of nickel ($Z = 28$) isotopes have been intensively studied over the last decades. The main reason for this interest is represented by the possibility to test the evolution of the single-particle structure between the sub-shell closure $N = 40$ (^{68}Ni)

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towards the expected double-magic ^{78}Ni. From a theoretical point of view the evolution of the nuclear structure in this region can be understood in terms of the monopole component of the tensor force [1], in particular for the case of the copper isotopic chain, for which a gradual reduction in energy of the $\pi f_{5/2}$ orbital with an increasing of the neutron number occupying the $g_{9/2}$ orbitals was observed [2]. The same theoretical approach predicts the inversion of the $\pi p_{3/2}$ and $\pi f_{5/2}$ orbitals around $N = 45$. Experimentally, this phenomenon is confirmed by nuclear moment measurements [3].

2. Experimental set-up and preliminary results

The studied nuclei were produced by the fragmentation of a primary beam of ^{86}Kr at incident energy of 60.4 A MeV in a Be target at the GANIL facility. The fragments were separated in flight using the LISE2000 spectrometer. Isotope identification was performed by combined measurements of the energy loss, magnetic rigidity and Time of Flight (TOF) on an event-by-event basis. At the implantation set-up two high-purity Ge detectors and a LEPS were placed in a compact geometry. In this paper, we present the preliminary results regarding the nuclear structure of ^{75}Cu.

In 2010, Daugas *et al.* [4] reported the existence of two isomeric states in ^{75}Cu, placed in coincidence based on their decay patterns. In Fig. 1, the delayed γ-ray spectrum obtained in the present experiment, representing the contribution of all three germanium detectors and conditioned by the identification of ^{75}Cu, is shown. The half-lives associated to the two observed transitions — as shown in Fig. 2 — were measured to be 310(8) ns for the 61.7 keV and 149(6) ns, for the decay curve of the 66.2 keV, in good agreement with the previously reported results in [4]. The values were extracted using a fit procedure with one, respectively two exponential convoluted with a Gaussian function, representing the detector time response, with a $\sigma = 60$ ns. The production rate achieved, made it possible to apply

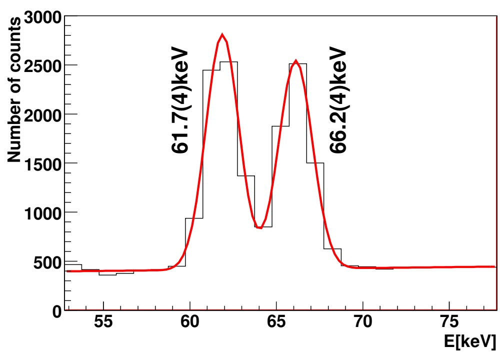

Fig. 1. Gamma spectrum associated to the implantation of ^{75}Cu.

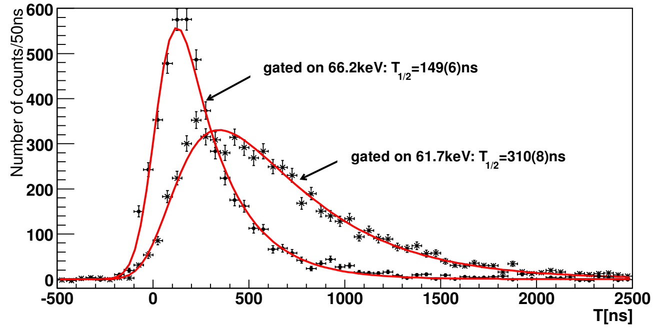

Fig. 2. Background subtracted time spectrum for the two transition observed for ^{75}Cu.

γ–γ coincidence techniques. A minimum number of coincidences of 125 was expected, according to the statistics obtained, the efficiencies of the germanium detectors used and supposing the level schemes given in [4]. However, the analysis performed showed the non-existence of a coincidence relation between the two known γ-rays. Based on this new information and knowing the spin and parity of the ground state [3], and also considering the low-energy states systematics for the odd copper isotopic chain two possible scenarios for the observed states are proposed, referred as A and B in Fig. 3. The above mentioned fit procedure for the decay of the lower

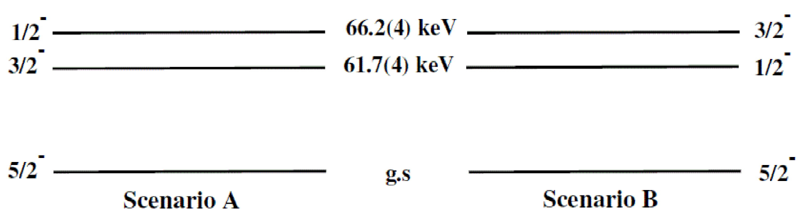

Fig. 3. Proposed level schemes for ^{75}Cu.

state indicates a quasi-null contribution for the direct feeding that might originate from the interplay between reaction mechanism and high-energy structure of ^{75}Cu. Assuming pure transition, the reduced transition probabilities were estimated starting from the observed gamma intensities. The obtained values are presented in Tables I and II, according to the two possible scenarios. The conversion coefficients used in the calculation were taken from [5]. A very good agreement between the low-energy levels predicted by shell model calculations for odd $^{69-73}$Cu isotopes and the experimental ones were obtained using an effective interaction that includes proton core excitation in valence space outside the ^{48}Ca core [6], which successfully reproduces the experimentally observed decrease in the magnetic moments of the $3/2^-$ ground state for the same isotopic chain. In the case of ^{75}Cu, a sequence of $5/2^-$(g.s.) $-$ $3/2^-(m1)$ $-$ $1/2^-(m2)$ states is predicted, with a energy difference of 3 keV between the first two excited states, in accordance with the energy level schemes proposed in this paper. The reduced transition probabilities given by this interaction, corresponding to the two proposed scenarios, are presented in the Tables I and II.

TABLE I

Transition rates in proposed scenario A.

E_γ keV	Transition	Type	α	$B(M1)$ W.u.	$B(E2)$ W.u.	SM
4.5	$1/2^- \to 3/2^-$	$M1$	50(30)	0.008(6)		0.081
66.2	$1/2^- \to 5/2^-$	$E2$	2.9(1)		30(2)	20
61.7	$3/2^- \to 5/2^-$	$M1$	0.201(5)	$2.43(8) \times 10^{-4}$		0.017
4.5	$1/2^- \to 3/2^-$	$M1$	50(30)	0.02(1)		0.081
66.2	$1/2^- \to 5/2^-$	$E2$	2.9(1)		17(1)	20
61.7	$3/2^- \to 5/2^-$	$E2$	3.76(11)		22(1)	3.3

TABLE II

Transition rates in proposed scenario B.

E_γ keV	Transition	Type	α	$B(M1)$ W.u.	$B(E2)$ W.u.	SM
4.5	$3/2^- \to 1/2^-$	$M1$	50(30)	0.03(2)		0.04
66.2	$3/2^- \to 5/2^-$	$M1$	0.166(4)	$7.5(6) \times 10^{-5}$		0.017
61.7	$1/2^- \to 5/2^-$	$E2$	3.76(11)		22(1)	20
4.5	$3/2^- \to 1/2^-$	$M1$	50(30)	0.02(1)		0.04
66.2	$3/2^- \to 5/2^-$	$E2$	2.9(1)		17(1)	3.3
61.7	$1/2^- \to 5/2^-$	$E2$	3.76(11)		22(1)	20

In both scenarios for the 4.5(6) keV transition only a $M1$ multipolarity is considered, the large life-time associated with an $E2$ transition type not being consistent with the data. Regarding the comparison of the experimental values for this transition with shell-model results in scenario A the difference between the two is one order of magnitude, while considering the level scheme proposed in scenario B the experimental value agrees well with the predicted one. The small $B(M1; 3/2^- \to 5/2^-)$ value indicates the partial persistence of the single particle character of those states, while the hindrance of the $B(M1; 3/2^- \to 1/2^-)$ reflects the gain in collectivity of the $1/2^-$ state with the filling of the $\nu g_{9/2}$ orbital. It will be interesting to see how well this interaction manage to reproduce the experimentally

$B(M1)$ known for this chart region, in order to differentiate between the proposed scenarios. One should also notice the fact that the experimental $B(E2; 1/2^- \to 5/2^-)$ values are close to the shell-model results regardless on the scenario considered.

A good agreement between the predicted values using the same interaction with the experimental values for the measured $B(E2; 3/2^- \to 5/2^-)$ in odd $^{69-73}$Cu isotopes was reported in [5]. In the case of ^{75}Cu reported in the present paper, the fact that the extracted values are significantly larger than the calculated ones — in both scenarios — can be interpreted as an indication of a mixed $M1 + E2$ transition.

3. Summary

We have shown the existence of two close low-lying isomeric levels in ^{75}Cu at excitation energies of 61.7 keV and 66.2 keV. The previous shell-model calculations describe correctly the observed isomeric states [6]. The comparison between theoretical predictions and the deduce transition rates reflects the gain in collectivity in the $3/2^-$ and $1/2^-$ states, while supporting the single-particle nature of the $5/2^-$ ground state as indicated in [4, 6]. The implications of these new results in defining the level scheme of this nucleus are in progress by means of large scale shell-model calculations.

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