Low energy isomeric levels of nuclei near N=40

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Abstract. 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 g⁹/² orbital with increasing number of neutrons is one of the key points in defining the structure of these nuclei at low excitation energy. The nuclei of interest were produced by fragmentation of a ⁸⁶Kr beam at 60MeV/u on a thick Be target at GANIL (France). Preliminary results on ⁷⁵Cu and ⁷⁸Ga isomers will be presented together with tentative spin and parity assignments.

1. Introduction

One of the compelling questions in nuclear physics is the evolution of single-particle states around shell closures when moving into a region of nuclei with unusual proton-to neutron ratio. In particular the nuclear structure and decay properties of neutron-rich nuclei in the vicinity of the magic nuclei ⁶⁸Ni have been intensively investigated over the last decade [1]. The comparison between shell-model calculations using different nucleon-nucleon interaction with the existing experimental results has shown the importance of tensor force effects in understanding the structure of nuclei around Z≈28 and N>40. The importance of the monopole term of the tensor force was pointed out by Otsuka et al.[2,3] in understanding the evolution of the nuclear structure in this region of the nuclear chart. The lowering of the πf⁵/² orbital was predicted, while the energy of the πf⁷/² increases when the neutrons start filling the g⁹/² orbital. The same theoretical estimation predicted the cross over between π 2p⁹/² and πf⁵/² around N=45, given the repulsive character of the tensor force. This was experimentally proven by Flanagan and Mane using laser spectroscopy techniques for copper and gallium isotopic chains [4, 5].

2. Experimental Set-up
In order to investigate the shell evolution near $^{68}$Ni towards the doubly magic $^{78}$Ni, neutron-rich nuclei were produced by the fragmentation reaction of a primary beam of $^{86}$Kr at the incident energy of 60.4 MeV/A on a Be target. The cocktail beam was separated in flight using the LISE2000 spectrometer by means of the energy loss and magnetic rigidity. Isotope identification was performed by combined measurements of the energy loss, magnetic rigidity and Time-of-Flight (TOF) in an event-by-event basis. At the focal plane, the ions were implanted in a 75 µm kapton foil inclined at 70°. Behind this foil a position sensitive Si detector was used in order to reject the events associated with the fragments that were not stopped in the foil. Two high-purity Ge detectors and a LEPS surrounded the implantation set-up in a very compact geometry. In this paper we present the preliminary results regarding the nuclear structure of $^{75}$Cu and $^{78}$Ga.

### 3. Results

#### 3.1 $^{75}$Cu

This nucleus was previously studied by Daugas *et al.*[6], showing the existence of two isomeric states. In the case of this previous experiment, $\gamma$-$\gamma$ coincidences studies were not possible due to low statistics, the two observed gammas were being placed in coincidence by means of time spectra, which for the low isomeric state clearly indicates a feeding from the above state. In this experiment due to higher statistics it was possible to construct $\gamma$-$\gamma$ coincidence matrix. The result by gating with the two transitions can be seen in figure 1. It can be observed that the two gammas are not in coincidence, the peaks present in the spectra correspond to random coincidences associated to the Compton scattering of 137.5 and 82 keV transition, from to the decay of $^{75}$Cu, which was the main contaminant in the identification matrix.

![Figure 1. Gamma coincidence spectra gated on 61.7(2) keV (left) and 66.0(2) keV (right). In the inset the decay curves of both transitions are shown.](image)

The lifetimes associated to the two observed transition were measured to be 310(8) ns for the 61.7(2) keV and 149(6) ns, for the decay curve of the 66.0(2) keV, respectively. From fitting the decay of low-lying isomeric state with a sum of double-exponential function convoluted with a Gaussian function (representing the detector response function), it has been proven that this transition is populated mainly from the decay of the isomeric state above. These lifetimes translate into the following reduced transition probabilities (assuming pure transitions multipolarity) : $B$(M1)=$1.0(4)\times10^{-4}$ W.u, $B$(E2)=$32(11)$ W.u for the 66.0(2) keV transition, and $B$(M1)=$2.43(4)\times10^{-4}$ W.u, $B$(E2)=$221(1)$ W.u for the 61.7(2) keV transition, respectively.

The known spin and parity of the ground state and given the low energy state systematics for the odd copper isotopic chain give rise to two possible scenario for this two low-lying states observed (scenario A and scenario B, figure 2).
3.2 $^{78}\text{Ga}$

Previous studies performed on this nucleus indicate the existence of an isomeric state of 499.2(4) keV of 110(6) ns, which decays via three transitions towards lower excited states [7]. More recent studies performed at ISOLDE by Mane using laser spectroscopy assigned a $2^-$ as spin and parity for the ground state of this nucleus [5]. The delayed gamma ray-spectrum associated to this nucleus is presented in Figure 3, the existence it can be seen of a new transition of 211.3(5) keV, unobserved so far.

$$
\begin{array}{c}
\text{M1} \\
\text{M1} \\
\text{M1}
\end{array}
\begin{array}{c}
\text{1/2-} \\
\text{3/2-} \\
\text{5/2-}
\end{array}
\begin{array}{c}
\text{E2} \\
\text{M1} \\
\text{M1} \\
\text{M1}
\end{array}
\begin{array}{c}
\text{3/2-} \\
\text{1/2-} \\
\text{5/2-}
\end{array}
$$

**Figure 2:** Proposed experimental spin assignment scenario A and B

The interpretation of the obtained values for the reduced transition probabilities and their implication on the nuclear structure of this nucleus is still in progress by means of large scale shell model calculation.

$\gamma-\gamma$ coincidence matrix conditioned by the decay of $^{78}\text{Ga}$ and gated by the known transition of this nucleus showed the fact that this new transition is in coincidence with the first excited state of 280.4(2) keV, which implies the existence of a new state of 491.8(3) keV, below the isomeric state. The obtain half-life of 110(5) ns for this state indicated the fact that this transition is also populate in the decay of the isomeric state and the existence of a transition of 6.6 (3) keV between the two. The comparison between the calculated reduced transition probabilities and systematics for this mass region near the shell closure $Z=28$, gives the most probable transition multipolarity for the observed gamma rays: M2 for the 498.9(8)keV, a transition type E2 for the 218.4(2) and 157.5(2) keV, while for the 6.6(3)keV a multipolarity of E2 is proposed.

**Figure 3:** Delay gamma ray spectrum associated to $^{78}\text{Ga}$. Inset: decay curve of new observed 211(4) keV transition.
4. Summary
A new level scheme was proposed for $^{75}$Cu based on $\gamma-\gamma$ coincidence results, as for $^{78}$Ga a new observed gamma transition has been seen observed from the decay of the known isomeric state. Based on this new observation and knowing the ground state spin and parity, a new level scheme is proposed. The implications of those new results in understanding the structure of studied nuclei are in progress by means of large scale shell model calculation.

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