LIFETIME MEASUREMENTS IN NEUTRON-RICH Cu ISOTOPES*

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(Received January 30, 2013)

The nuclear structure of neutron-rich nuclei close to the double-magic nucleus ^{78}Ni has been investigated by measuring the lifetime of excited states. In this contribution, it will be presented the lifetime of the $J^{\pi} = 7/2^{-}$ excited state at 981 keV of the ^{71}Cu isotope, measured using the AGATA Demonstrator coupled to the PRISMA spectrometer and the Köln plunger setup. This is the first time this combined setup has been used for a lifetime measurement.

DOI:10.5506/APhysPolB.44.505
PACS numbers: 21.10.Tg, 23.20.Lv, 21.10.Pc

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 27–September 2, 2012.

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1. Introduction

Magic numbers are a key feature in finite Fermion systems since they are strongly related to the underlying mean field. Their existence and their stability suggested the presence of closed shell configurations which led to the development of the Shell Model of atomic nuclei. Recent theoretical calculations [1] and experimental results [2] have indicated that magic numbers can change depending on where they lie on the nuclear chart due to the residual nucleon–nucleon interaction, in particular due to the residual tensor interaction ($\sigma\tau$), thus implicating a more local applicability of the concept of magic number. The tensor component of the residual interaction is expected to depend strongly on the filling of the orbital near the Fermi surface [3]. The nature of the monopole part of the tensor interaction is such that an attraction (repulsion) is expected for orbitals with anti-parallel (parallel) spin configuration. Such a mechanism is predicted to cause modifications into the known shell gaps with their possible weakening or disappearance. In particular, it is predicted that the $Z = 28$ gap for protons in the pf-shell becomes smaller moving from ^{68}Ni to ^{78}Ni as a result of the attraction between the proton $f_{5/2}$ and the neutron $g_{9/2}$ orbits and repulsion between the proton $f_{7/2}$ and neutron $g_{9/2}$ configurations, thus modifying or even inverting the effective single particle states [1, 3–5].

Neutron-rich Cu isotopes, having one proton outside the $Z = 28$ shell, are good probes of the single particle structure in the region of ^{78}Ni. The characterization of their excited states allows searching for possible shell modifications due to the tensor mechanism mentioned above. β-decay and Coulomb excitation studies have provided detailed information on the excited states of the neutron-rich Cu isotopes up to $A = 73$ [6–10] giving several candidates for states of mainly single particle character $\pi f_{5/2}$, $\pi f_{7/2}$ and $\pi p_{1/2}$. In particular, in Ref. [8] the single-particle nature of the $J^\pi = 5/2^-$ state for ^{71,73}Cu isotopes has been confirmed with the measurement of the reduced transition probabilities by Coulomb excitation. In the same work, the $J^\pi = 1/2^-$ states have been identified as low-lying collective states, while the $J^\pi = 7/2^-$ ones as particle-core states following identical behaviour in their $(A-1)$ Ni neighbouring nuclei. The present experimental work aims to determine the collective or single particle character of the $J^\pi = 7/2^-$ state at 981 keV in ^{71}Cu through a lifetime measurement, which will provide essential information to characterize the $Z = 28$ shell gap. Its spin and parity have been assigned to be $J^\pi = 7/2^-$ in the work of Franchoo [7] based on beta-decay pattern as well as on calculations regarding the particle-core coupling [11].

2. Experimental details

A multi nucleon transfer reaction between a ^{76}Ge beam of 577 MeV energy impinging on a ^{238}U target of 1.4 mg/cm^2 with a 1.2 mg/cm^2 thick Ta backing has been used to populate the excited states for the nuclei of interest. The target was mounted together with a Nb degrader foil of 4.2 mg/cm^2 thickness in a compact plunger device, provided by the University of Cologne. The projectile-like reaction partners exit the target foil with an average energy of 375 MeV and results in a velocity of 30 μm/ps ($v/c = 10.5\%$). The Nb foil degrades the energy of the ions to 300 MeV and results in an average velocity of 28 μm/ps ($v/c = 9.3\%$). The difference in velocity is large enough to distinguish γ rays emitted before and after the degrader foil by their different Doppler shifts if an AGATA resolution of 2 keV at 500 keV and a minimum requirement of $2 \times$ FWHM for an acceptable separation between both peaks are assumed.

The projectile-like reaction products were detected and identified in the magnetic spectrometer PRISMA [12], which was positioned at 55° with respect to the beam axis, close to the grazing angle. Emitted γ rays were detected with the AGATA Demonstrator [13] located at backward angles, where sensitivity for Doppler lifetime measurements is good. Only four of the five clusters, located at 18.1 cm from the target position, were available for the experiment. Therefore, the efficiency of the system was 3.2% at 1.332 keV.

The lifetime of the $7/2^-$ excited state at 981 keV for the ^{71}Cu is expected to be of the order of several picoseconds and, therefore, we have made use of the Recoil Distance Doppler Shift method (RDDS) [14, 15]. In particular, a new approach of this method [16, 17] has been used in this work profiting from the performances of PRISMA. The use of an ion tracking spectrometer, where A and Z are determined in an event-by-event basis, allows to determine the lifetime using only one of the peaks, the shifted or the unshifted one. In this way, the normalization can be done considering the number of nuclei populated in the reaction and detected in PRISMA (N_0) instead of using the addition of the number of counts of both peaks as it is done in the conventional method. The main difference between both methods is that in the conventional one, the intensity of both peaks has to be measured, but in the second one, the determination is done in terms of only one of the measured peaks.

In order to cover a range from approximately 2 to 30 ps, the range of the expected lifetime of the state, measurements have been taken for five different target-degrader distances: 112 μm, 212 μm, 512 μm, 1012 μm and 1912 μm.

3. Experimental results

The nucleus ^{71}Cu is a neutron-rich isotope six neutrons away from the last stable copper isotope. The accessibility to this nucleus, specially for in-beam experiments, is difficult. In the present measurement, ^{71}Cu corresponds to a very weak channel in the multi nucleon transfer reaction performed ($-2p, -3n$ channel) and, therefore, the population is low. Only the $7/2^-$ and $5/2^-$ states at 981 and 534 keV, respectively, have been populated. The total isotope yield distribution measured with PRISMA is shown in Fig. 1.

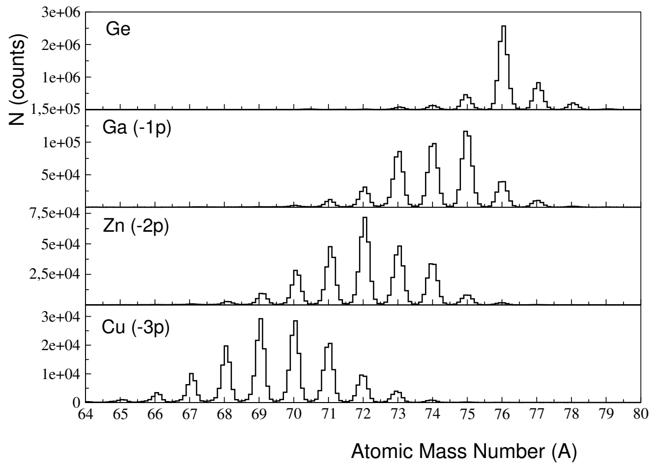

Fig. 1. Isotope yield for Ge, Ga, Zn and Cu. The statistics shown consider all distances measured in the experiment.

For the lifetime analysis of the $7/2^-$ state at 981 keV, only three target-degrader distances have been used: 112 μm, 212 μm and 512 μm since the lifetime is quite short. Figure 2 shows the spectra for the ^{71}Cu in the region of interest.

The new approach for the RDDS method, described in [16, 17] has been used for the lifetime determination. The performed fit used to determine the lifetime is shown in Fig. 3, where it can be seen the large uncertainty introduced for each distance due to the low statistics obtained in the measurement. The obtained value for the lifetime of the $7/2^- \rightarrow 3/2^-$ transition at 981 keV for the ^{71}Cu is $\tau = 20(16)$ ps, giving a value of $B(E(2\downarrow)) = 3(2)$W.u. for the reduced transition probability.

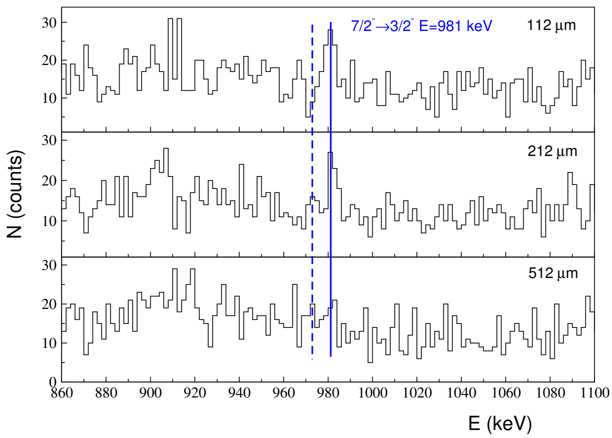

Fig. 2. Doppler corrected γ-ray spectra for ^{71}Cu in the region of interest, *i.e.*, for the $7/2^- \rightarrow 3/2^-$ transition at 981 keV for the three relevant distances. The solid line stands for the unshifted peak and the dashed line for the shifted one.

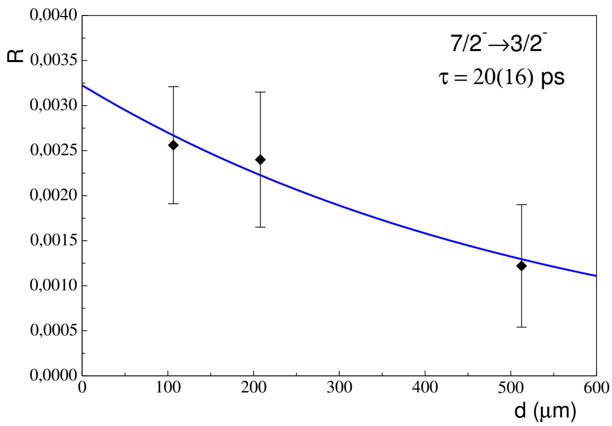

Fig. 3. Fit for the lifetime determination for the $7/2^- \rightarrow 3/2^-$ transition with 981 keV. The new approach, where the unshifted peak is normalized to the number of ions detected in PRISMA, has been used. In the plot, d corresponds to the target-degrader distance and R to the ratio between the number of counts measured in the unshifted peak ($I_{\rm u}$) and the number of ^{71}Cu isotopes detected in PRISMA (N_0).

4. Summary and conclusions

The lifetime of the $7/2^-$ exited state at 981 keV of the ^{71}Cu isotope has been measured using the AGATA Demonstrator coupled to the PRISMA spectrometer and the plunger setup through the Recoil Distance Doppler

Shift Method. The measured value for the reduced transition probability indicates a single-particle character of the state. The extended Shell Model interpretation will be presented in future publications.

This work has been partially supported by the grants FPA2008-06419, FPA2008-03774, AIC10-D-000605, AIC-D-2011-0764 and Consolider CSD2007-00042 from the Spanish Government and by INFN Italy.

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