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g-factors of isomeric states in the neutron-rich nuclei

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Abstract. We report the results from the first experiment to measure gyromagnetic factors of μs isomers in neutron-rich nuclei produced by intermediate-energy projectile-fragmentation reactions. The Time Dependent Perturbed Angular Distribution (TDPAD) method was applied in combination with the heavy-ion–gamma correlation technique. The nuclides in the vicinity of ^{68}Ni were produced and spin-oriented following the fragmentation of a ^{76}Ge, 61.4 MeV/u beam at GANIL. The results obtained, $|g|(^{69\mathrm{m}}\mathrm{Cu}) = 0.225(25)$ and $|g|(^{67\mathrm{m}}\mathrm{Ni}) = 0.125(6)$ provide another indication of the importance of proton excitation across the $Z = 28$ shell gap for the description of these states.

PACS. 21.10.Ky Electromagnetic moments – 23.20.En Angular distribution and correlation measurements – 25.70.Mn Projectile and target fragmentation

1 Introduction

Magnetic moments are very sensitive probes to particular components of the nuclear wave function. Their dependence on the isospin, spin and orbital angular momentum of the involved valence nucleons can give us additional criteria for the spin/parity assignment of the nuclear state and serve as a stringent test to the nuclear models.

There are some principle experimental difficulties for the nuclear-structure studies of the neutron-rich nuclear species which are related to the methods of production. The combinations of stable beams and targets do not provide the opportunity to produce nuclides on the neutron-rich side of the nuclear chart by means of fusion-evapora- tion reactions. Therefore, some other production mechanisms, like deep-inelastic scattering or projectile-fragmentation reactions, can be used. Here we report the first application of the TDPAD method to measure the g-factor of microsecond isomeric states in neutron-rich nuclei, produced in projectile-fragmentation reactions at intermediate energies.

2 Experimental details and results

A primary necessity for a TDPAD measurement is to obtain a spin-aligned ensemble. It was reported for the first time by Schmidt-Ott *et al.* [1]. Another important point is to preserve the orientation during the passage of the ions through the spectrometer and before their implantation in the measurement host. The misalignment between the orientation axis and the beam direction at the implantation point should be also considered [2]. Some peculiarities of the TDPAD method, details of the data analysis

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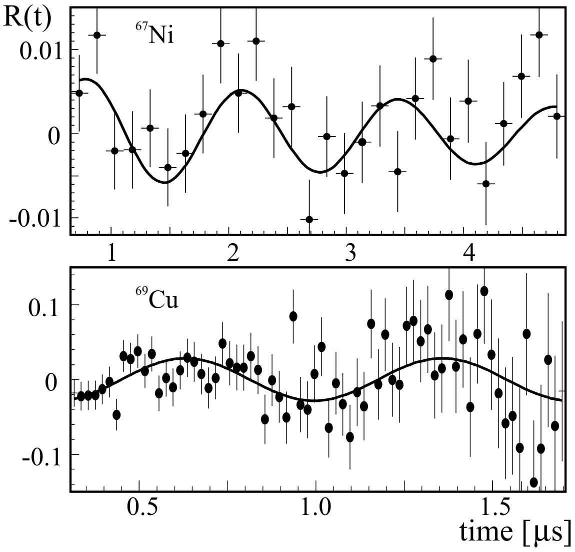

Fig. 1. $R(t)$ functions for the 313 keV transition in ^{67}Ni (upper part) and for the sum of the 190 keV, 471 keV and 680 keV transitions in ^{69}Cu (lower part).

and extended discussion of the experimental results can be found in ref. [3]. Here we are going to present only schematically the results obtained.

The experiment was performed at GANIL where the fragmentation of a 61.4 MeV/u ^{76}Ge beam was used in order to produce the nuclei in the vicinity of ^{68}Ni. A 145 mg/cm^2 Be target was positioned at the entrance of the LISE spectrometer. Immediately at its exit, in the first focal plane, we positioned the TDPAD setup. The nuclei of interest were implanted in a high-purity Cu foil. Two Ge CLOVER detectors and three BaF$_2$ fast scintillators, positioned in a horizontal plane around an electromagnet which provided a constant magnetic field ($B = 375(7)$ mT) in vertical direction, were used to monitor the isomeric decay as a function of time. More details and a schematic view of the setup can be found in ref. [3]

Using the data from the Ge CLOVER detectors, we derived the $R(t)$ functions for certain γ transitions from the isomeric decay of ^{67}Ni ($J^\pi = 9/2^+$, $E_x = 1007$ keV, $T_{1/2} = 13.3$ μs) and ^{69}Cu ($J^\pi = 13/2^+$, $E_x = 2741$ keV, $T_{1/2} = 0.35$ μs), presented in fig. 1. Applying also Fast Fourier Transform (FFT) and autocorrelation analysis (for the case of $^{67\mathrm{m}}$Ni) we obtained the final results $|g|(^{67\mathrm{m}}\mathrm{Ni}) = 0.125(6)$ and $|g|(^{69\mathrm{m}}\mathrm{Cu}) = 0.225(25)$. Reported error bars include the statistical uncertainty plus the inhomogeneity of the magnetic field over the beam spot (approximately 1×2 cm). Knight-shift and paramagnetic corrections are expected to be negligible, compared to the other uncertainties and were not taken into account.

3 Discussion

In order to compare the results obtained with the theoretical expectations, we performed shell-model calculations in a spherical basis using the S3V [4] and the modified Hjorth-Jensen *et al.* [5] interactions. ^{56}Ni was considered as an inert core and the model space included the $p_{3/2}$, $f_{5/2}$, $p_{1/2}$ and $g_{9/2}$ orbitals. For the ^{69}Cu case, no more than 5 particles in $g_{9/2}$ were allowed. The model space was not additionally truncated for ^{67}Ni. Effective g-factors ($g_l^{\text{eff.}} = g_l^{\text{free}}$, and $g_s^{\text{eff.}} = 0.7 g_s^{\text{free}}$), used for the theoretical calculations, provided better agreement with the experimental results.

Two $13/2^+$ states appear very close in energy in the ^{69}Cu calculations. They both have strongly mixed nature. One of them has a predominant $\pi p_{3/2} \otimes \nu f^5_{5/2} g_{9/2}$ configuration, while for the other the $\pi p_{3/2} \otimes \nu p_{1/2} g_{9/2}$ contribution is most pronounced. In the calculations using the S3V interaction we obtained the effective g-factor for the state with predominant $\pi p_{3/2} \otimes \nu f^5_{5/2} g_{9/2}$ character (which is lower in energy) $g = +\ 0.228$ and $g = +0.256$ for the other $13/2^+$ state. Using the modified Hjorth-Jensen *et al.* interaction, the relative positions of the levels are inverted and the g-factors obtained are $g^{\text{eff.}} = +0.212$ and $g^{\text{eff.}} = +0.242$. The theoretical calculations are in good agreement with the experimental result, but due to the very similar values of the g-factors of the two states one cannot claim a specific configuration of the experimentally observed $13/2^+$ level.

^{67m}Ni was expected to present a simple case of a single neutron hole in the proposed [6] doubly magic ^{68}Ni core. On the other hand, the results from some recent measurements of g-factors and transition probabilities of 2_1^+ states in some Ni isotopes [7,8] were reproduced only after proton excitation across the $Z = 28$ shell gap was considered. In our calculations we obtained, respectively, $g^{\text{eff.}} = -0.284/-0.290$ for the S3V and the modified Hjorth-Jensen *et al.* interactions. These values differ by a factor of two from the experimentally derived g-factor. At this moment it was proposed [9] that an $M1$ (spin flip) excitation across the $Z = 28$ shell gap might account for the observed g-factor. We performed schematic two-level mixing calculation, in the approach of ref. [10], which showed that about 2% admixture of $\pi(f^{-1}_{7/2} f_{5/2})_{1^+} \otimes \nu g_{9/2}$ configuration into the supposed pure $\nu g_{9/2}$ wave function is sufficient to explain the experimental value. This is another case which hints the importance of the proton excitation across $Z = 28$ for the understanding of the structure of the Ni isotopes. Although this calculation is quite schematic, it shows the extreme sensitivity of the g-factor observable towards specific components of the nuclear wave function.

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