INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **31** (2005) S1439–S1442 doi:10.1088/0954-3899/31/10/010

g-factor measurement of the $9/2^+$ isomeric state in ^{65}Ni

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Received 19 March 2005
Published 12 September 2005
Online at stacks.iop.org/JPhysG/31/S1439

Abstract

We report on the first measurement of the g factor of the $J^\pi = 9/2^+$ isomeric state in ^{65}Ni. (d,p) reactions on enriched ^{64}Ni and ^{62}Ni have been used in order to populate and spin orient the $J^\pi = 9/2^+$ isomeric states in ^{65}Ni and ^{63}Ni. The hyperfine field of the Ni target, oriented by an external magnetic field, was used in order to obtain a sufficient number of spin precessions within the relatively short life time of the isomers. The g factor obtained, $g(^{65m}\mathrm{Ni}) = -0.296(3)$, is in good agreement with the g factors of other $9/2^+$ states in the region and with shell-model calculations.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Nuclear magnetic moments are very sensitive probes to the single-particle component of the nuclear wavefunction. One often uses them as a stringent test of nuclear theories and to verify our understanding of nuclear properties in the vicinity of shell closures. Next to a doubly magic nucleus, one expects the extreme single-particle picture to be most valid and therefore the observed nuclear magnetic moments to be very close to the Schmidt values. Following the trend of the magnetic moments through a chain of semi-magic nuclei, one can try to get an insight into the nuclear properties and the double-magic points.

Nickel is the only element in Nature where three doubly magic nuclei are observed (^{48}Ni, ^{56}Ni and ^{78}Ni) and the double-magic character of a fourth one (^{68}Ni) is under discussion (see, e.g., [1] and the references therein). Following the trend of the nuclear magnetic moments in the Ni isotopes, one should be able to pin down the doubly magic nuclei. The $\nu g_{9/2}$ orbital appears as an intruder in the fp shell and it plays an important role in the low-energy structure of the neutron-rich Ni nuclei. It manifests itself as an isomeric state from ^{63}Ni onwards that allows us to study the g factors of the $J^{\pi} = 9/2^{+}$ states towards ^{68}Ni. The g factors of these states in ^{63}Ni [2] and ^{67}Ni [3] have been previously measured and here we report on the first measurement of the $9/2^{+}$ isomeric state in ^{65}Ni.

2. Experimental details

In order to measure the g factor of the $J^{\pi} = 9/2^{+}$, $E_x = 1017$ keV isomeric state in ^{65}Ni we have applied the time dependent perturbed angular distribution (TDPAD) method. The isomeric state was populated and spin oriented using a (d,p) reaction on an enriched (>95%) ^{64}Ni target. A pulsed deuteron beam with a repetition period of 400 ns and integral intensity of less than 1 nA was provided by the Tandem facility of Orsay, France. The target was positioned between the poles of an electromagnet, providing an external magnetic field of 0.05 tesla in the vertical direction. This field was used in order to orient the internal hyperfine field in the Ni target giving a total magnetic field at the nuclear site

$$B_{\text{tot}} = B_{hf} + (1 + K)B_{\text{ext}} \tag{1}$$

where B_{hf} is the hyperfine field, B_{ext} is the external applied field and K is the Knight shift, usually of the order of a few per cent, which can be neglected in this case. In order to determine B_{hf} of Ni in Ni at room temperature we have performed a TDPAD measurement on the ^{63m}Ni ($9/2^{+}$), which has a known g factor [2], using an enriched ^{62}Ni target. The obtained hyperfine field will be discussed later.

Two Ge coaxial detectors and two BaF$_2$ scintillator detectors, positioned in a horizontal plane, were used to monitor the gamma-ray intensity as a function of time. The Ge detectors were positioned at ±135° and the BaF$_2$ ones at ±45° with respect to the beam direction. The experimental signature in a TDPAD measurement is usually obtained by taking the difference between two detectors, positioned at 90° with respect to each other, and normalizing to their sum. It is known as the $R(t)$ function;

$$R(t, \theta, B) = \frac{I(t, \theta, B) - I(t, \theta + \pi/2, B)}{I(t, \theta, B) + I(t, \theta + \pi/2, B)} = \frac{3A_2B_2}{4 + A_2B_2}\cos\{2(\theta - \omega_L t)\}. \tag{2}$$

Here A_2 is the angular-distribution coefficient, B_2 is the orientation parameter and θ is the respective angle for each detector combination.

Each gamma ray detected in any of the detectors triggered the data acquisition and also served as a start signal for a time-to-digital-converter. The stop signal was correlated to the beam chopper. Each event, accepted by the data acquisition, consisted of an energy and time signal for each detector that has fired within the 400 ns time window between two beam pulses, and was recorded in an event-by-event mode. In the off-line analysis we have constructed time spectra, conditioned by the energy of the transitions below the isomeric state. An example of energy spectrum for the ^{64}Ni (d,p) ^{65}Ni reaction is presented in figure 1. Using the sum of the time spectra conditioned by the energy of the isomeric transition we have obtained the half-life of the isomeric state $t_{1/2} = 22(2)$ ns in agreement with the previously reported value 18.5(7) ns [4]. Similarly for the $9/2^{+}$ isomeric state in ^{63}Ni we have obtained $t_{1/2} = 10(1)$ ns, which is in agreement with [2, 5] but differs from the value adopted in [6] of 3.33(21) ns.

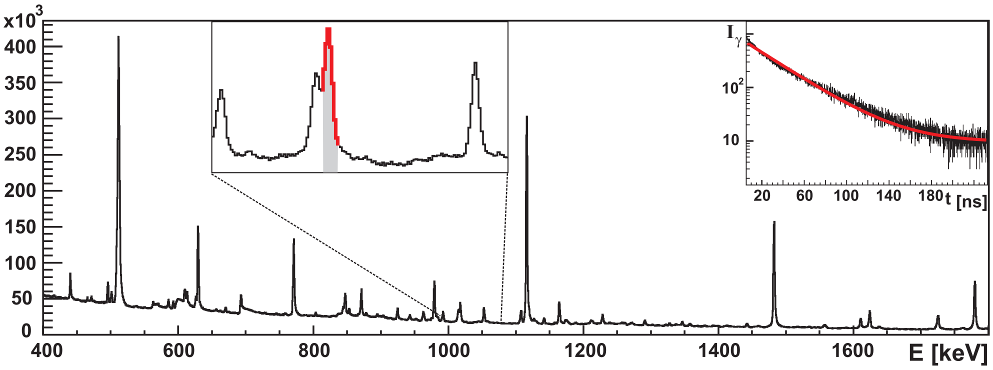

Figure 1. Energy spectrum for the ^{64}Ni (d,p) ^{65}Ni reaction. As an inset is presented a zoom on the isomeric transition and its time spectrum.

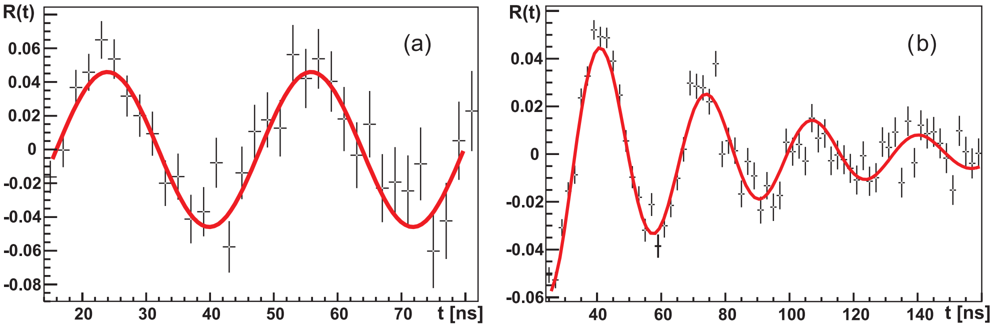

Figure 2. $R(t)$ functions for the combination of two Ge (a) and two BaF$_2$ (b) detectors.

In order to ensure a good control over the hyperfine field in the Ni targets we have annealed them and have also measured their magnetization. This has shown that 0.03 T external field, in the direction of the foil, is enough to orient it completely. Using the known $g(^{63m}\mathrm{Ni}, 9/2^+) = -0.269(3)$ [2] we have determined a total magnetic field at the nuclear site $B_{\mathrm{tot}} = 6.92(9)$ T. Taking into account the negative sign of the HF of Ni in Ni and $B_{\mathrm{ext}} = 0.05$ T in our case, this would result in $B_{hf} = -6.97(9)$ T (see equation (1)). An NMR measurement of the temperature dependence of the HF field of Ni in Ni [7] reports $B_{hf} = -6.9505(3)$ T at room temperature. This higher precision value was used in order to determine the magnetic field at the nuclear site. The value that we have adopted is $B_{\mathrm{tot}} = 6.90(2)$ T. Its uncertainty is a conservative estimate of the possible variation of the HF field due to different target treatments.

The specific positioning of the gamma-ray detectors (±135° and ±45°) allowed us to derive the $R(t)$ function not only between two different detectors, positioned at 90°, but also to use the same detector with two different directions of the magnetic field (positive and negative). In this way we have minimized the systematic uncertainty and obtained several independent $R(t)$ functions. Each of these data sets gave consistent pictures which allowed us to combine them for the final determination of the g factor. From the $R(t)$ functions of the combined sets, an example is presented in figure 2, we have determined $g(9/2^+, ^{65}\mathrm{Ni}) = -0.2962(24)_{\mathrm{stat}}(9)_{\mathrm{syst}}$, where the statistical uncertainty comes from the χ^2 fit to the $R(t)$ functions and the systematic one is due to the magnetic field determination.

The damping of the amplitude of the $R(t)$ function in the BaF$_2$ detector combination is due to the considerable β-decay background contribution into the energy gate of the isomeric transition.

3. Results and discussion

The experimentally determined $g_{\text{exp}}(9/2^+, {}^{65}\text{Ni}) = -0.296(3)$ is very well in agreement with the g factors of other neutron $9/2^+$ states in the region. This allows us unambiguously to identify the isomeric state as having a predominant $\nu g_{9/2}$ configuration. Large scale shell model calculations [8] using the ^{48}Ca core and allowing up to 5 *ph* excitations provide a value $g_{\text{theo}} = -0.303$. This agrees very well with the experimentally determined g factor especially considering that free-nucleon g factors were used for its derivation.

Acknowledgments

We are grateful to the Orsay Tandem engineers for providing us the beam in stable conditions, to the IN2P3/EPSRC French/UK loan pool for providing the Ge detectors, to J Meersschaut for performing the magnetization measurements of the targets and to M Hass for providing the electromagnet. This work has been partially supported by the INTAS project No. 00-0463 and the IUAP project P5/07 of the Belgian Science Policy Office.

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