g-factors measurement of magnetic rotation band in ^{85}Zr*

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Abstract The magnetic-rotational band in ^{85}Zr was populated by the fusion-evaporation reaction ^{60}Ni(^{28}Si, 2pn)^{85}Zr with a 98 MeV Si beam from the HI-13 tandem accelerator at China Institute of Atomic Energy. The g-factors of the high spin states of this magnetic rotation band in ^{85}Zr were measured by the TMF-IMPAD method for the first time. The measured g-factors decrease with the increasing of spin. It implies that the valence neutron alignment is more rapid than that of the valence proton, which leads to a decrease of g-factors along the band.

Key words ^{85}Zr, Magnetic rotation, g-factor, TMF-IMPAD

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1 Introduction

Traditional rotational bands characterized by strong E2 transitions are related to nuclear deformation, and the spherical or near-spherical nuclei show spectra of single-particle excitations[1]. The magnetic rotation is a new mode of nuclear rotation occurring in near-spherical nuclei with small deformation. For rotational bands to occur, the spherical symmetry of a quantal system must be broken, the magnetic rotation M1 transitions band arises from a spontaneous symmetry breaking by anisotropic currents of a few excited nucleons[2,3]. At the band head, the spins of the valence proton and neutron are coupled perpendicularly. Angular momentum along the magnetic rotation bands is generated by a step-by-step alignment of the valence proton and neutron spins into the direction of the total angular momentum. The valence proton and neutron vectors form the blades of a pair of shears, when the valence nucleons spins are fully aligned, the highest-spin state is formed and the band is terminated. Magnetic rotation band resembles the closing of the blades of a pair of shears and, hence, is called the shears band[4,5]. The first theoretical explanation for the magnetic-rotation was provided by the tilted axis cranking (TAC) model[6,7].

In recent years magnetic rotations of strongly enhanced magnetic dipole (M1) transitions have been observed in near-spherical nuclei in several mass regions. So far, the “shears band or shears mechanism” has been investigated only by measuring the lifetimes of the magnetic states and the B(M1) values of the magnetic transitions[6,8]. The measurement of g-factors can give detailed information about the coupling scheme and the configuration of the shears states. The shears mechanism of a step-by-step alignment of the high-spin particle and hole orbitals can be confirmed well by measuring g-factors of magnetic ro-

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tational intra-band states. The g-factor of the band-head ($29/2^-$, 2584 keV, $T_{1/2}$=9 ns) of the M1 band in ^{193}Pb has been measured using the time differential perturbed angular distribution (TDPAD) method[9] only up to now. The g-factors of high spin intra-band states have not been measured, which can vividly describe the shears mechanism of magnetic rotation.

The magnetic-rotational band with a ΔI=1 rotational structure in ^{85}Zr has been proposed by Wang Zhimin et al[10]. S. K. Tandel et al also investigated this band and calculated the TRS [11] that indicates a smaller deformation. Fig. 1 shows the decay scheme of ^{85}Zr and the negative parity magnetic-rotational band built on the $17/2^-$ state[10]. In order to confirm the shears mechanism of magnetic rotation, the g-factors of the magnetic-rotational intra-band states in ^{85}Zr have been measured by the transient magnetic field-ion implantation perturbed angular distribution (TMF-IMPAD) method for the first time[12,13].

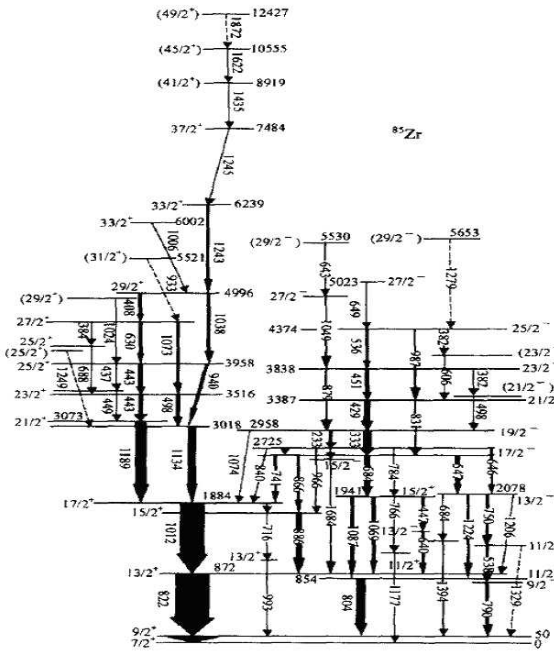

Fig. 1. ^{85}Zr decay scheme taken from Ref. [10].

2 Experimental and data analysis

The g-factors of high spin states in the magnetic-rotational band built on the $17/2^-$ state in ^{85}Zr were determined by the TMF-IMPAD method. The details of the method are described in Refs. [12,13]. The magnetic-rotational states in ^{85}Zr were populated by the fusion-evaporation reaction ^{60}Ni(^{28}Si,2pn)^{85}Zr with a 98 MeV Si beam from the HI-13 tandem accelerator at China Institute of Atomic Energy. The reaction cross section calculated by the Cascade program is 160 mb at 98 MeV. The target consisted of a ^{60}Ni-Fe-Cu three-layer. The target layer of ^{60}Ni enriched to 99.6% was evaporated onto a defect-free natural Fe-layer of 1.51 mg·cm^{-2}, the thickness of the target layer was 0.439 mg·cm^{-2}. A Cu stopper layer with a 12 mg·cm^{-2} thickness was evaporated on the other side of Fe-layer. After evaporation the target assembly was annealed to make the Cu stopper layer defect-free. The ^{85}Zr recoiling nuclei with an average velocity of 0.026 c passed through the Fe-layer in a 0.34 ps traverse time and stopped in the Cu stopper layer. The ferromagnetic Fe-layer was polarized by a 0.17 T magnetic field whose direction was perpendicular to the beam-detector plane and periodically reversed (up and down) every 120 seconds. During the ^{85}Zr nuclei moved through the polarized Fe-layer, they experienced a transient magnetic field with higher than 10^3 T resulting in the nuclear precess around the direction of the transient magnetic field. The nucleus completed its decay to the ground state in the perturbation-free Cu stopper. The emitted γ rays were detected by four BGO Compton suppressed HPGe detectors with a $\sim$30% efficiency placed in the beam-detector plane at $\theta_1 = \pm 60°$ and $\theta_2 = \pm 120°$ with respect to the beam direction. The γ-γ coincidence data were recorded in a five-parameter event-by-event mode by the Kodaq data acquisition system based on CAMAC. The five parameters are specified by the polarizing field direction and the γ ray energy detected by 4 detectors, respectively.

The data analysis program constructed eight singles spectra according to 4 detectors and polarizing field directions. In case that γ ray peaks of interest were not well separated, eight gated spectra were created. A typical singles spectrum recorded in one of four detectors at a polarizing field direction and the 200—480 keV part of the same spectrum gated by the 822 keV transition are shown in Fig. 2, respectively. The nuclear precession of a state was inferred from a double ratio obtained through the single ratios $\rho(\pm\theta_i)$, which were formed with the counts of an adjacent pair of detectors at $\pm\theta_i$ for a observed transition[12,14]. The counts were obtained from the singles or gated spectra.

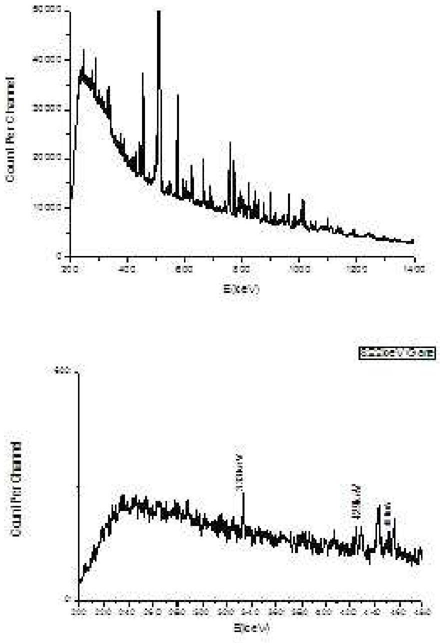

Fig. 2. γ-ray singles spectrum recorded in a detector (up) and 200—480 keV part of the same spectrum gated by 822 keV (down).

The precession angle $\Delta\phi$ depends on the nuclear g-factor and the experienced transient magnetic field strength $B_{\text{TMF}}(t)$:

$$\Delta\phi = -(g\mu_{\text{N}}/\hbar)\int_{\text{en}}^{\text{ex}} B_{\text{TMF}}(t)\text{e}^{-\tau/t}\text{d}t, \tag{1}$$

where μ_{N} is the nuclear magneton and τ is the mean lifetime of nuclear state. The integration runs over the entry to exit times of the recoiling ions for the passage through the Fe-layer. $\Delta\phi$ is given by $\Delta\phi = \varepsilon/S(\theta)$, where ε is achieved from the double ratio ρ and $S(\theta) = (1/W(\theta))(\text{d}W(\theta)/\text{d}\theta)$ is the logarithmic slope of γ-ray angle distributions. The transient magnetic field $B_{\text{TMF}}(t)$ can be obtained from the parameterization given by Shu et al[15]:

$$B_{\text{TMF}}(v) = 926(v/v_0)^{0.45}T, \tag{2}$$

where v_0 is the Bohr velocity and v is the velocity of recoiling nucleus. $B_{\text{TMF}}(t)$ is instantaneous velocity or time dependent. When the lifetime of nuclear state is several times greater than the traverse time in Fe-layer, the Eq. (1) can be expressed as:

$$\Delta\phi = -(g\mu_{\text{N}}/\hbar)\int_{\text{en}}^{\text{ex}} B_{\text{TMF}}(t)\text{d}t. \tag{3}$$

The high spin states of magnetic dipole band in ^{85}Zr have the lifetimes greater than the 0.34 ps traverse time, i.e. the recoiled nuclei of ^{85}Zr are stopped in the Cu stoper, and then the g factor for a given nuclear state can be obtained using Eq. (3) with the measured $\Delta\phi$. In the preset case all the lifetimes of the magnetic rotational states are greater than the transition time of 0.34 ps.

In data reduction the precession transfer was taken into account. Referring to MagMo program[16], a computer program was written for precession transfer correction of ε. The precession-transfer-corrected $\varepsilon_{\text{corr}}$ was used in obtaining precession and g-factor of a state.

3 Results and discussion

Table 1 lists the precessions and g-factors experimentally measured for the first four intra-band states along the band in ^{85}Zr. The g-factor of the $23/2^-$ state can not be corrected for the precession transfer because the weakly populated higher level transitions were not observed. The g-factor vs. spin are shown in Fig. 3.

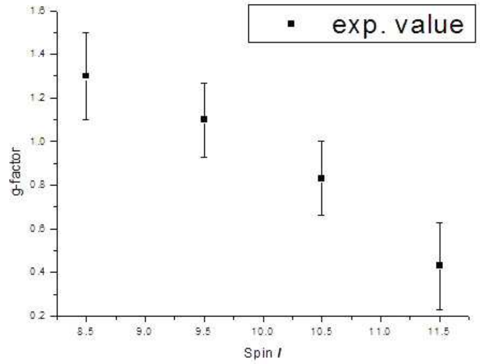

Fig. 3. The measured g-factors vs spin for magnetic-rotational states in ^{85}Zr.

Table 1. Precessions and g-factors for magnetic-rotational states in ^{85}Zr.

transition	E_γ/keV	double ratio ρ	ε	$\varepsilon_{\text{corr}}$	precession/mrad	g-factor
$17/2^-\rightarrow 15/2^+$	684	0.9907	0.004687	0.008802	31.6	1.30
$19/2^-\rightarrow 17/2^-$	333	0.9913	0.004378	0.007089	26.8	1.11
$21/2^-\rightarrow 19/2^-$	429	0.9923	0.003877	0.005492	20.3	0.83
$23/2^-\rightarrow 21/2^-$	451	0.9942	0.002928		10.5	0.43

As Wang Zhimin et al[10] pointed out that the magnetic rotational band in ^{85}Zr is a three-quasiparticle band with negative parity, and the parity of the band is negative, the configuration of the magnetic rotational band is presumably composed of two $g_{9/2}$ valence nucleons and a f-shell valence nucleon. The g-factor of the band head is closed to the single particle g-factor value of $g_{9/2}$ proton. It strongly implies that the g-factor of band head is mainly contributed by the $g_{9/2}$ valence proton. As shown in Fig.3, the g-factors decreases with increasing the spin. This gives a picture that the valence neutron alignment towards the total angular momentum is faster than the proton alignment. The rapid alignment of valence neutrons leads to a decrease of g-factors along the band.

4 Summary

The g-factors of the first 4 states along the magnetic rotational band built on the $17/2^-$ state in ^{85}Zr have been measured by the TMF—IMPAD method for the first time. The decreasing of the g-factors with the spin is observed, implying that the valence neutron vector alignment towards the total angular momentum vector is faster than that of the vector proton vector. The TAC model calculation is ongoing in order to extract the band configuration and the shears angles.

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