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Study of magnetic-rotation in ^{82}Rb by *g*-factor measurements*

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Abstract Magnetic rotation in ^{82}Rb has been investigated for the first time by g-factor measurement of intra-band states of the magnetic-rotational band built on the 11- state. The g-factors were measured by a TMF-IMPAD method and calculated by a semi-classical model of independent particle angular momentum coupling assumption. The g-factors and deduced shears angles decrease with the increasing of spin along the band, illustrating a step-by-step alignment of the valence protons and neutrons. The rapid alignment of the valence neutrons leads to a decrease of g-factors. The present results vividly reveal the shears mechanism of magnetic rotation.

Key words ^{82}Rb, magnetic rotation, shears mechanism, g-factor

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1 Introduction

The magnetic rotation is a novel nuclear rotation occurring in nuclei with nearly spherical shape. Magnetic-rotational band is characterized by magnetic dipole (M1) transitions. The angular momentum vector of the valence proton particles is perpendicular to that resulting from the valence neutron holes at the band head of magnetic rotation[1]. The resulting proton and neutron vectors form the blades of a pair of shears and the total angular momentum increases by closing the blades of these shears along the band. Hence, the magnetic rotational band is called the shears band[2]. As the spins of particles and holes are fully aligned, the highest-spin state is formed and the band is terminated. The magnetic rotation has been described theoretically by the tilted axis cranking (TAC) model[3] and the residual interaction between proton and neutron[4].

The shears mechanism of a step-by-step alignment of the high-spin particle and hole angular momenta can be well investigated by measuring g-factors of magnetic rotational states. The g-factor or magnetic moment is very sensitive to the proton and neutron alignments. The g-factors of high-j protons are positive and large due to the substantial contribution from orbital angular momentum. Since there is no orbital contribution g-factors of high-j neutrons are negative and small. The g-factors are expected to vary systematically as the shears close or the spin goes up in the magnetic-rotational band. Therefore, g-factors of intra-band states can provide direct evidence of shears mechanism of magnetic rotation.

^{82}Rb (Z=37, N=45) lies in the mass region of transition from deformed to spherical shapes and is particularly suitable for studying magnetic rotation. The magnetic rotational band in ^{82}Rb has been observed by H. Schnare et al[5], R. Schwengner et al[6] and J. Döring et al[7]. Fig. 1 shows the decay scheme of the negative parity ΔI=1 magnetic-rotational band built on the 11- state in ^{82}Rb.

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netic rotation in ^{82}Rb by measuring g-factors of four intra-band states of magnetic rotation for the first time.

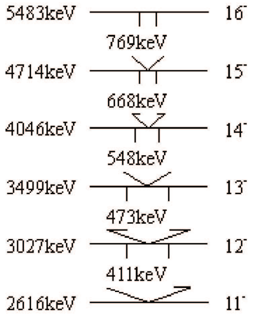

Fig. 1. ^{82}Rb magnetic-rotational band decay scheme.

2 Experimental details

The g-factors of four intra-band states in the magnetic-rotational band built on the 11- state in ^{82}Rb were determined by the TMF-IMPAD (transient magnetic field-ion implantation perturbed angular distribution) method[8, 9]. The magnetic-rotational states in ^{82}Rb were populated by the fusion-evaporation reaction ^{60}Ni(^{27}Al,4pn) ^{82}Rb with a 130 MeV Al beam from the HI-13 tandem accelerator. The reaction cross section obtained with a PACE4 program[10] is ~40 mb at 130 MeV.

The schematic drawing of the TMF-IMPAD set-up is shown in Fig. 2[8]. A three layer target assembly of ^{60}Ni-Fe-Cu and a Ta beam stopper 2 mm from the target in the down stream were located in a "T" shaped bronze target chamber between the two pole tips of the polarizing electromagnet. The three layer target assembly was made in such a way that a 0.439 mg·cm^{-2} target layer of ^{60}Ni enriched to 99.6% was evaporated onto a well annealed natural Fe layer of 1.51 mg·cm^{-2}, on the other side of which a Cu stopper layer of 12 mg·cm^{-2} was evaporated. The ^{82}Rb recoiling nucleus with an average velocity of 0.028~0.029c passed through the Fe layer in a 0.35 ps traverse time and stopped in the Cu stopper layer. The ferromagnetic Fe layer was polarized by a 0.16 T magnetic field, the direction of which was perpendicular to the beam-detector plane and automatically reversed up and down every 120 seconds during the measurement. As the ^{82}Rb nucleus moved along the polarized Fe layer, it experienced a transient magnetic field of ~1.56×10^{3} T, and the nuclear precession about the magnetic field direction took place. 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 placed in the beam-detector plane at $\theta = \pm 60°$ and $\theta = \pm 120°$ with respect to the beam direction. The γ-γ coincidence data were recorded in a five-parameter event-by-event mode. The five parameters are specified by the field direction and the 4γ-ray detectors.

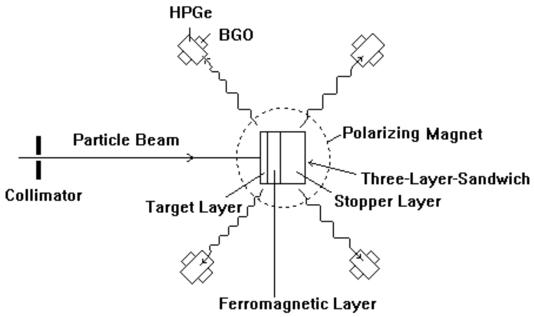

Fig. 2. Schematic drawing of TMF-IMPAD set-up.

In data analysis eight singles spectra were constructed according to 4 detectors with two polarizing field directions. In case γ ray peaks of interest are not well separated, gated spectra were generated. The nuclear precession of a state was inferred from a double ratio obtained through single ratios $\rho(\pm\theta_i)$ formed with the counting rates of an adjacent pair of detectors at $\pm\theta_i$ for a observed transition[8, 11]. The γ ray counts were obtained from the singles or gated spectra. The precession angle $\Delta\phi$ can be obtained by

$$\Delta\phi = \varepsilon / S(\theta) \ , \tag{1}$$

where the term ϵ is an experimental ratio defined as

$$\varepsilon = \frac{\rho - 1}{\rho + 1} \tag{2}$$

and $S(\theta)$ is the logarithmic slope of γ-ray angular distribution:

$$S(\theta) = \frac{1}{W(\theta)} \frac{\mathrm{d}W(\theta)}{\mathrm{d}\theta} \ . \tag{3}$$

The nuclear g factor can be inferred from the precession angle $\Delta\phi$ and the transient magnetic field strength $B_{\mathrm{TMF}}(t)$ experienced by a nucleus:

$$\Delta\phi = -(g\mu_{\mathrm{N}}/\hbar) \int_{\mathrm{en}}^{\mathrm{ex}} B_{\mathrm{TMF}}(t) \mathrm{e}^{-t/\tau} \mathrm{d}t \ , \tag{4}$$

where μ_{N} is the nuclear magneton and τ is the mean lifetime of nuclear state. The transient magnetic field $B_{\mathrm{TMF}}(t)$ is given by the Shu's parameterization[12]

$$B_{\mathrm{TMF}}(t) = 926(\nu/\nu_0)^{0.45} T \ , \tag{5}$$

where ν_0 is the Bohr velocity and ν is the velocity of a recoiling nucleus. A computer program was written and used for precession transfer correction[13].

3 Result and discussion

A semi-classical model based on the independent particle angular momentum coupling assumption was used to determine the configuration and calculate the g-factors and shears angles of the intra-band states[4]. Four-quasi particle configuration $\pi(g_{9/2})^2\otimes\pi(p_{3/2},f_{5/2})\otimes\nu(g_{9/2})$ was obtained from the measured g-factors. Fig. 3 shows the measured and calculated g-factors. They are in good agreement within the experimental error and decline with the increasing of spin. Note that the configuration $\pi(p_{3/2})\otimes\pi(g_{9/2})^2\otimes\nu(g_{9/2})$ can give g-factors only up to spin 14.

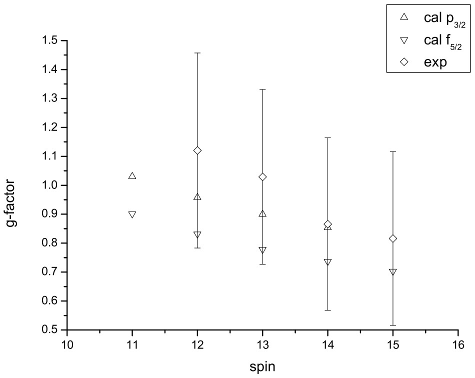

Fig. 3. Measured and calculated g-factors along magnetic-rotational band in ^{82}Rb.

As shown in Fig. 4, the calculated shears angles θ between $\vec{j}_\pi$ and $\vec{j}_\nu$ of proton and neutron angular momenta decrease with the spin increasing along the band and the shears angle at the band-head is 88°. Fig. 4 also illustrates the calculated angle θ_π between the proton and total angular momenta. It can be known that the angle θ_ν between the neutron and total angular momenta contributes a great part to the shears angle change. The valence neutron alignment towards the total angular momentum is much faster than the proton alignment, leading to a decrease of g-factors along the band. The decreasing of both g-factors and shears angles with the spin increase indicates that the angular momentum along the magnetic-rotational band is generated by the shears effect of a step-by-step alignment of the high-spin valence protons and neutrons.

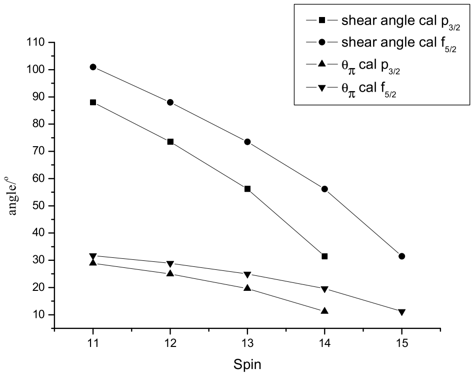

Fig. 4. Calculated shears angle θ and θ_π as a function of spin in ^{82}Rb.

4 Conclusion

Magnetic rotation has been studied for the first time by the g-factor measurement of the magnetic-rotational band built on the 11- state in ^{82}Rb. The g-factors were also calculated by a semi-classical model of independent particle angular momentum coupling assumption on the basis of the 4 qp configuration $\pi(g_{9/2})^2\otimes\pi(p_{3/2},f_{5/2})\otimes\nu(g_{9/2})$. Both g-factors and shears angles decrease with the increasing of spin in the band, illustrating that the angular momentum along the magnetic-rotational band is generated by the shears effect of a step-by-step alignment of the high-spin valence protons and neutrons. The rapid alignment of the valence neutron angular momentum towards the total angular momentum leads to a decrease of the g-factors along the band. The present results provide vivid evidence for the shears mechanism of magnetic rotation.

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