Magnetic moment measurements of mirror nuclei ^{12}B and ^{12}N*

ZHENG Yong-Nan(郑永男)[1] ZHOU Dong-Mei(周冬梅)[1] YUAN Da-Qing(袁大庆)[1] M. Mihara[2]
K. Matsuta [2] M. Fukuda[2] T. Minamisono[3] T. Suzuki[4] ZHANG Xi-Zhen(张锡珍)[1]
ZUO Yi(左翼)[1] XU Yong-Jun(徐勇军)[1] ZHU Jia-Zheng(朱佳政)[1] WANG Zhi-Qiang(王志强)[1]
LUO Hai-Long(骆海龙)[1] FAN Ping(范平)[1] ZHU Sheng-Yun(朱升云)[1]

1 (China Institute of Atomic Energy, Beijing 102413, China)
2 (Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan)
3 (Fukui University of Technology, Fukui 910-8505, Japan)
4 (Department of Physics, College of Humanities and Sciences,Nihon University, Sakurajosui 3-25-40, Setagaya-ku, Tokyo 156, Japan)

Abstract The spin polarized β-emitting mirror nuclei ^{12}B($I^{\pi}=1^{+}, T_{1/2}=20.18$ ms) and ^{12}N($I^{\pi}=1^{+}, T_{1/2}=$ 11 ms) are produced by the low nuclear reactions ^{11}B(d,p) ^{12}B and ^{10}B(^{3}He,n)^{12}N and by selecting the projectile energy and the recoil angle. Their magnetic moments are measured by the β-NMR technique. The magnetic moments obtained after Knight shift correction are $\mu(^{12}\mathrm{B}) = 1.001(17)\mu_{\mathrm{N}}$ and $\mu(^{12}\mathrm{N}) = 0.4571(1)\mu_{\mathrm{N}}$. The calculation using the existing shell model could not reproduce the measured magnetic moments for ^{12}B and ^{12}N simultaneously.

Key words β-emitting mirror nuclei ^{12}B and ^{12}N, spin polarization, β-NMR, nuclear magnetic moment

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1 Introduction

The production and maintenance of nuclear polarization are a key point for measurements of nuclear magnetic and electric quadruple moments of β-emitting nuclei by the β-NMR and β-NQR technique. This can be realized by the selection technique of the projectile energy of the producing nuclear reaction and the recoil angle of the produced β-emitting nuclei and by the application of a strong magnetic field.

The nuclear magnetic moment is one of fundamental physical quantities depicting nuclear structure and the measurement of magnetic moments plays an important role in nuclear structure studies. Nuclear structure of stable nuclei can be well described by the shell model. It is interesting to know whether the existing shell model can be used to describe nuclear structure of unstable nuclei. Therefore, the magnetic moments of β-emitting mirror nuclei ^{12}B($I^{\pi}=1^{+}, T_{1/2}=20.18$ ms) and ^{12}N($I^{\pi}=1^{+}, T_{1/2}=11$ ms) have been measured by the β-NMR technique in order to know whether the shell model can be directly used for unstable nuclei. If the shell model calculation can reproduce the magnetic moments of mirror nuclei ^{12}B and ^{12}N simultaneously, this is a robust indication that the shell model without modification can describe nuclear structure of unstable nuclei.

2 Experimental details

In the β-NMR and β-NMR measurements a

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1) E-mail: zhusy@ciae.ac.cn

sensitive indicator of resonance is the asymmetry of emitted β-rays. The angular distribution of β-rays emitted by spin-polarized unstable nuclei is anisotropic, while isotropic for un-polarized unstable nuclei. Therefore, angular distribution of β-rays emitted by polarized unstable nuclei becomes isotropic as polarization is fully destroyed by applying a rf signal that satisfies the resonance condition. Fig. 1 shows change of angular distribution of β-rays emitted with rf on and rf off or far away from the resonance. The resonance can be determined by the measurement of the asymmetry of β-ray angular distribution.

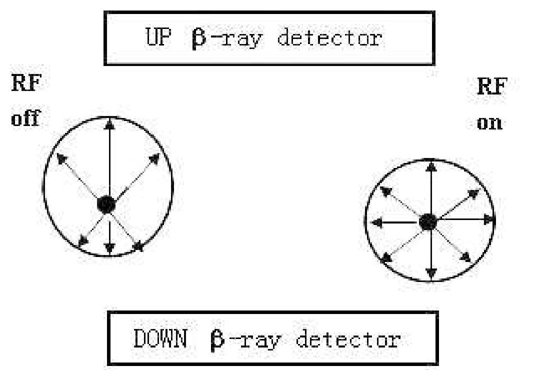

Fig. 1. Angular distribution of β-rays with rf on and off.

The spin-polarized unstable β-emitting nuclei can be produced by the projectile fragmentation reaction or the low energy nuclear reaction. In the projectile fragmentation process the spin polarization of β-emitting nuclei are obtained by selecting the angle and the momentum of ejected fragments[1, 2]. In the low energy reaction process polarization of product nuclei is achieved by selecting the recoil angle and incident particle energy[3]. In the present work the low energy reaction method is employed to produce the polarized mirror nuclei ^{12}B and ^{12}N.

In the low energy nuclear reaction the target thickness causes an energy distribution and hence a charge state distribution of recoil nuclei, leading to hyperfine coupling due to unpaired electrons and holes until arrival of a stable charge state. This hyperfine coupling destroys polarization. Decoupling of hyperfine interaction between the nuclear and atomic spins can be implemented by applying a strong magnetic field parallel to the polarization direction in a region that covers the reaction target and the catcher into which the recoil nuclei are implanted. Therefore, the nuclear polarization is persisted until β-ray emission at the catcher[4].

The β-NMR and β-NQR technique consists of production and implantation of polarized unstable β-emitting nuclei into a catcher, detection of polarization in terms of β-ray asymmetry determined by using a pair of β-ray telescope detectors, usually up and down detectors as shown in Fig. 1 and destruction or inversion of spin-polarization by applying a rf signal with specific resonance frequency. The details of β-NMR and β-NQR measurements can be found in Ref. [5].

The β-emitting mirror pair nuclei $^{12}\mathrm{B}(I^{\pi} = 1^{+}, T_{1/2} = 20.18\ \mathrm{ms})$ and $^{12}\mathrm{N}(I^{\Pi} = 1^{+}, T_{1/2} = 11\ \mathrm{ms})$ were produced by the nuclear reactions $^{11}\mathrm{B}(d,p)^{12}\mathrm{B}$ at the incident deuteron energy $E_{\mathrm{d}} = 1.5$ MeV and $^{10}\mathrm{B}(^{3}\mathrm{He,n})^{12}\mathrm{N}$ at the incident helium energy $E_{\mathrm{He}} = 3.0$ MeV. Natural boron targets were used. The thickness of boron target evaporated in vacuum on the 0.5 mm thick Ta backing was in a range of 200—250 g/cm^2. The target was attached on a target holder that was cooled by water flow. The glancing angle of the target was 5° to the incident beam. The ^{12}B nuclei were recoiled into a Cu catcher of 10 μm at the angle of 32°—48° and the ^{12}N nuclei into a Pt catcher of 100 μm at the angle of 12°—28°. The nuclear spin was polarized at these incident particle energies and recoil angles. To preserve the produced polarization and perform the β-NMR detection the Cu and Pt catchers were placed in a strong magnetic field of H=2.17 kG and 5.00 kG, respectively. A pulsed rf magnetic field was applied perpendicular to the externally applied magnetic field H. The emitted β-ray asymmetries of ^{12}B and ^{12}N were measured by a pair of plastic-scintillation counter telescopes placed at 0° and 180° with respect to the polarization direction (see Fig. 1). In order to reduce un-wanted backgrounds the beam was pulsed by a beam chopper. The widths and repetition periods of beam pulse were 25 ms and 80 ms and 16 ms and 40 ms, respectively for ^{12}B and ^{12}N. A beam pulse was followed by a 3 ms rf pulse for ^{12}B and 2 ms for ^{12}N. The β-ray counting started at the end of the rf pulse and lasted to the next beam pulse. The measurements for ^{12}B and ^{12}N were performed at China Institute of Atomic Energy and Osaka University, respectively.

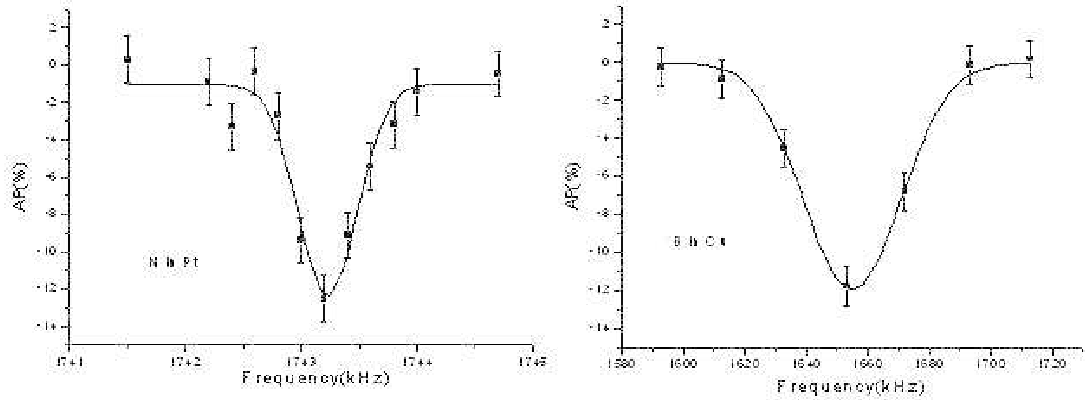

Fig. 2. Typical β-NMR spectra for ^{12}B and ^{12}N.

3 Result and discussion

Figure 2 shows the typical β-NMR spectra for $^{12}\mathrm{B}(I^{\pi}=1^{+},T_{1/2}=20.18\,\mathrm{ms})$ and $^{12}\mathrm{N}(I^{\pi}=1^{+},T_{1/2}=11\,\mathrm{ms})$. It can be seen that the polarization of 12% was achieved for both ^{12}B and ^{12}N. The least-squares fitting of the spectra gave the resonance frequencies ν_{L} = 1.655 (28) MHz and ν_{L} = 1.7432 (3) MHz, respectively, for $^{12}\mathrm{B}(I^{\pi}=1^{+},T_{1/2}=20.18$ ms) and $^{12}\mathrm{N}(I^{\pi}=1^{+},T_{1/2}=11$ ms). The magnetic moment can be obtained from $\nu = h\nu_{\mathrm{L}}I/\mu_{\mathrm{N}}H$ where I is the spin, H is the applied magnetic field and μ_{N} is the nuclear magneton. The experimentally measured magnetic moments are $\mu(^{12}\mathrm{B}) = 1.001(17)\mu_{\mathrm{N}}$ and $\mu(^{12}\mathrm{N}) = 0.4571(1)\mu_{\mathrm{N}}$ after the Knight shift correction.

We have performed the shell model calculation, which could not reproduce the magnetic moments for ^{12}B and ^{12}N simultaneously. The CK and PSDMK2 calculations gave $\mu = 0.599\mu_{\mathrm{N}}$ and $\mu = 0.399\mu_{\mathrm{N}}$ for ^{12}B and $\mu = 0.778\mu_{\mathrm{N}}$ and $\mu = 0.976\mu_{\mathrm{N}}$ for ^{12}N. The calculation using an improved shell-model Hamiltonia with the enhanced spin-flip proton-neutron interaction and modified single-particle energies is under way.

4 Summary

The magnetic moments of the mirror nuclei pair $^{12}\mathrm{B}(I^{\pi}=1^{+},T_{1/2}=20.18\,\mathrm{ms})$ and $^{12}\mathrm{N}(I^{\pi}=1^{+},T_{1/2}=11\,\mathrm{ms})$ have been measured by the β-NMR technique. The spin polarized β-emitting mirror nuclei ^{12}B and ^{12}N were produced by the low energy nuclear reactions $^{11}\mathrm{B}(d,p)^{12}\mathrm{B}$ and $^{10}\mathrm{B}(^{3}\mathrm{He},\mathrm{n})^{12}\mathrm{N}$. The magnetic moments obtained after Knight shift correction are $\mu(^{12}\mathrm{B}) = 1.001(17)\mu_{\mathrm{N}}$ and $\mu(^{12}\mathrm{N}) = 0.4571(1)\mu_{\mathrm{N}}$. The calculation of the existing shell model could not reproduce the magnetic moments for ^{12}B and ^{12}N simultaneously.

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