Development of β-NMR with spin-aligned beam

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Nuclear electromagnetic moments, namely magnetic dipole (μ) and electric quadruple (Q) moments, are one of the most sensitive probes to address a single-particle configuration and nuclear deformation, respectively. So far, nuclear moments for ground states have been measured by the method of β-ray-detected nuclear magnetic resonance (β-NMR) combined with a spin-polarized radioactive beam. However, it is difficult to apply β-NMR to far-unstable nuclei produced by BigRIPS because the spin polarization is significantly reduced for reactions with the removal of many nucleons and/or with a beam energy >100 MeV/nucleon. In order to overcome this difficulty, we have been developing a new method that combines the β-NMR technique and highly spin-aligned beam production with the two-step fragmentation method by using BigRIPS.[1)] This report presents the recent results of a demonstration experiment using spin-aligned ^{13}B ($T_{1/2}$ = 17.3 ms, I^{π} = $3/2^{-}$) with the known ground-state μ and Q moments.[3)]

The experiment was performed at the Heavy Ion Medical Accelerator in Chiba (HIMAC). A primary ^{15}N beam with an energy of 100 MeV/nucleon was accelerated by the synchrotron. The beam irradiation time was 20 ms in every 3.3 s. A radioactive ^{13}B beam was produced by the two-proton-removal reaction of ^{15}N with a 1-mm-thick Be target, which was located at the entrance of the secondary beamline SB2. The ^{13}B beam was separated by two dipole magnets and a wedge-type energy degrader (3-mm thickness, 6° angle) at the dispersive focal plane F1. The spin alignment was obtained by selecting a moment off the center of the momentum distribution by −4–−3%. Subsequently, the spin-aligned ^{13}B beam was delivered to the end of the beamline F3, where the β-NMR apparatus is located, and was implanted to a TiO_2 single crystal.

Since the Q moment of the implanted ^{13}B interacts with an electric filed gradient at the implantation site in the crystal and causes unequal Zeeman splitting between the individual sub-levels, a partial spin reversal using the adiabatic fast passage (AFP) method[2)] becomes possible and convert the spin alignment of the implanted ^{13}B into the spin polarization. Consequently, the angular distribution of the emitted β rays becomes anisotropic. For the AFP method, a static magnetic field of 0.2 T was applied to the crystal perpendicular to the beam axis in the horizontal plane, and an oscillating magnetic field was applied by a pair of coils perpendicular to the static magnetic field. The β rays from the β decay of ^{13}B were detected by two telescopes placed at 0° and 180° with respect to the direction of the static magnetic field. Each telescope consists of two 1.0-mm-thick plastic scintillators.

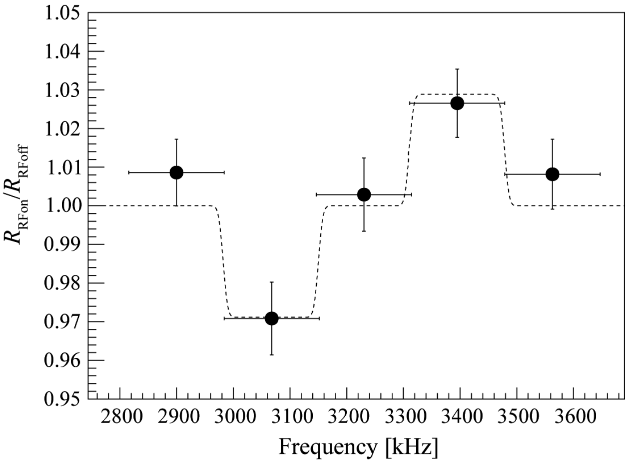

Fig. 1. Obtained NMR spectrum for spin-aligned ^{13}B. The ordinate of this spectrum shows the double ratio $R_{\mathrm{RFon}}/R_{\mathrm{RFoff}}$, where R_{RFon} (R_{RFoff}) is the ratio of the β-ray counts detected by the 0° and 180° telescopes with (without) the oscillating magnetic field. The dotted line is the spectrum expected from the literature values of $\mu = +3.1778(5)\ \mu_{\mathrm{N}}$ and $Q = +36.6(8)$ mb[3)] assuming a spin alignment of 4.5%.

Figure 1 shows the obtained NMR spectrum for spin-aligned ^{13}B. The resonances were observed at 3067 ± 84 kHz and 3394 ± 84 kHz, which correspond to the transitions between the Zeeman sub-levels with $m = -3/2$ and $-1/2$, $+1/2$, and $+3/2$, respectively. From these values, the moments of $^{13}\mathrm{B}_{\mathrm{g.s.}}$ were deduced to be $|\mu| = 3.18\ (9)\ \mu_{\mathrm{N}}$ and $|Q| = 36(9)$ mb, which are consistent with the literature values of $\mu = +3.1778(5)\ \mu_{\mathrm{N}}$ and $Q = +36.6(8)$ mb.[3)] We have successfully demonstrated our new method of β-NMR with a spin-aligned beam.

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