β-NMR measurement of unstable nuclei with cross-polarization technique

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A polarized solid proton target for RI beam experiments has been developed at RIKEN and the Center for Nuclear Study, University of Tokyo.[1)] By means of electron polarization in photo-excited triplet states of pentacene, proton polarization of approximately 20% has been achieved in a low magnetic field of 0.1 T and at a high temperature of 100 K. The target has been applied to RI beam experiments for several times.[2,3)] One of the next directions in the research is the polarization of unstable nuclei. If the polarization of protons can be transferred to unstable nuclei stopped in the target, measurements of magnetic moments would become possible with the β-NMR method. The polarization condition of high temperature and low magnetic field, which is the distinct advantage of the target, is indispensable in such low-energy beam experiments. In this article, we report on our attempt of transferring proton polarization to ^{13}C nuclei contained in the sample.

As a sample, we used a single crystal of p-terphenyl doped with pentacene molecules. Most of ^{1}H nuclei in p-terphenyl molecules were replaced by deuterium to obtain a higher ^{1}H polarization. The abundance of the ^{1}H was 2%. The weight of the sample was 28 mg. The crystal was irradiated by the pulsed laser light with a wavelength, an average power, pulse width, and repetition rate of 514 nm, 0.3 W, 13 μs, and 7.5 kHz, respectively. The sample temperature was controlled at 293 K by flowing cold nitrogen gas. The optimum power of the microwave was 3 W. Under these conditions, a proton polarization of 6.2±1.2% was obtained.

In the next step, the obtained ^{1}H polarization was transferred to the ^{13}C system by the cross-polarization method. The ^{13}C (or ^{1}H) spin rotates along the static magnetic field at a certain Larmor frequency. In the cross-polarization method, we apply a transverse magnetic field rotating with the Larmor frequency. This rotating field, produced by radio-frequency (RF) waves, effectively changes the level gap between spin up/down states. When the effective level gaps of ^{1}H and ^{13}C are equal, these systems couple to each other and polarization transfer takes place. The level gap is given as $\hbar\omega_R = \gamma\hbar H_{RF}$, where ω_R and γ are the Rabi frequency and gyromagnetic ratio, respectively. The H_{RF} is the strength of the rotating field, which is proportional to the square root of the RF power.

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In the present case, the Larmor frequencies of ^{13}C and ^{1}H are 3.167 and 12.59554 MHz, respectively, in a static field of 0.3 T. By irradiating these two RF waves at the same time and by tuning their powers to satisfy the Hartmann-Hahn condition, $\gamma^{\rm H}\hbar H^{\rm H}_{RF} = \gamma^{\rm C}\hbar H^{\rm C}_{RF}$, one can realize the polarization transfer between two systems. Here, the superscripts "H" and "C" represent ^{1}H and ^{13}C, respectively. By changing $H^{\rm C}_{RF}$ with fixed $H^{\rm H}_{RF}$, we searched the point where the Hartmann-Hahn condition is satisfied. The result is shown in Fig. 1 .

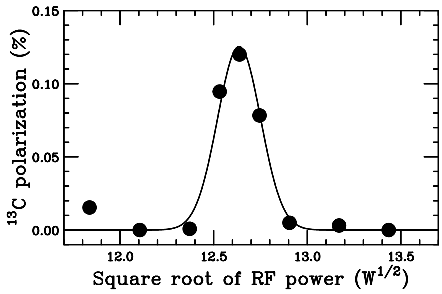

Fig. 1. The RF power dependence of ^{13}C polarization

As seen in the figure, the ^{13}C polarization was successfully obtained for the RF power of ∼160 W. The magnitude of ^{13}C polarization was 0.12 ± 0.05%. The polarization-transfer efficiency, which is the ^{13}C polarization divided by ^{1}H polarization (6.2%), is found to be 1.9%. While this value is not high, it is reasonable becouse the sample is deuterated and the abundance of ^{1}H is 2%. If the sample is not deuterated, the number of ^{1}H nuclei to which ^{13}C couples becomes 50 times larger. In that case, a polarization transfer efficiency of close to 100% would be obtained.

In conclusion, we obtained a high proton polarization of 6.2% bia temperature control and the use of a deuterated p-terphenyl crystal. By transferring the proton polarization, the ^{13}C polarization was successfully obtained with the cross-polarization method. The next step would be the polarization transfer to unstable nuclei stopped in the target. As the gyromagnetic ratio of the unstable nuclei is not precisely known, the parameter search for the Hartmann-Hahn condition will become more difficult. Finding an efficient method of the search is a challenge for the future.

References

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