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II-4 Magnetic Moment of β-Emitter ^{41}Sc

K. SUGIMOTO, A. MIZOBUCHI, T. MINAMISONO and Y. NOJIRI

Laboratory of Nuclear Studies, Faculty of Science, Osaka University, Toyonaka, Osaka 560

The nuclear magnetic resonance (NMR) on short-lived β-emitter ^{41}Sc ($I^{\pi} = 7/2^{-}$, $T_{1/2} = 0.59$ sec, $E_{\beta^{+}\mathrm{Max.}} = 5.4$ MeV) has been studied by utilizing the polarized recoil nuclei produced and implanted through a nuclear reaction and the resultant asymmetric β-decay. The essential part of the experimental technique was similar to that of previous works.[1] In the present experiment on ^{41}Sc, two kinds of techniques were introduced. One was the adiabatic passage method of NMR, in which the polarization was reversed so as to double the detectable change of the β-decay asymmetry.[2] The other was a cryogenic procedure to prolong the relaxation time T_1 in the implantation medium.

The nuclei ^{41}Sc were produced through the ^{40}Ca(d, n)^{41}Sc reaction by using the Osaka University 4MV Van de Graaff accelerator. The incident energy of deuteron was around 4 MeV. The experimental arrangement of the reaction chamber and the cooled recoil stopper are shown in Fig. 1. A thin layer of natural calcium metal ($\sim$40 μg/cm^2) was evaporated onto a copper backing and used as a target. The target wad cooled by a water flow at the back side and a high intensity beam of about 50 μA was used during the measurements. Recoil nuclei emitted from the target were selected by a recoil collimator at about 30° relative to the incident beam and allowed to strike a recoil implantation medium (recoil stopper). For the preservation of polarization, the decoupling magnetic field of about 7 kG was applied in the direction normal to the reaction plane.

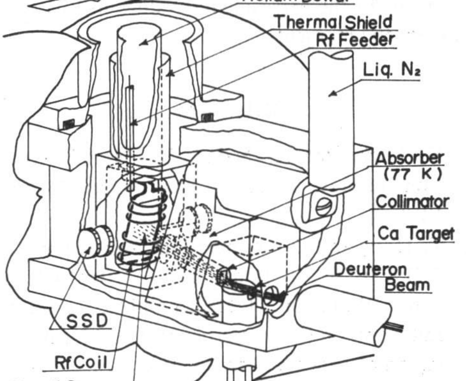

Fig. 1. Schematic view of the experimental arrangement.

A use of metallic foil was planned as a recoil stopper. The spin-lattice relaxation time T_1 for the elements of $Z \sim 20$ in a metallic environment was estimated to be order of $10^{-2} \sim 10^{-3}$ sec at room temperature. A liquid helium cryostat was constructed in which the recoil stopper could be cooled to 4.2 K. When a Pt foil was used at 4.2 K, the relaxation time of ^{41}Sc could be estimated to be longer than the nuclear lifetime. By using the known Knight shifts between the third group metals, we could estimate the Knight-shift ratio of B(III) and Sc(III) in plantinum metal. Since T_1T for ^{8}B in plantinum metal was found to be $\sim 10^3$ Ksec,[2] T_1T for ^{41}Sc in plantinum metal was estimated to be about 40 Ksec. On the other hand, T_1T for the very dilute Al in palladium metal has been known to be 24.8 Ksec.[3] This fact indicated that T_1T for ^{41}Sc in palladium metal might be 13 Ksec. Comparing the character of platinum with palladium, T_1T for ^{41}Sc in platinum should be larger than 13 Ksec and this value of T_1T was consistent with that estimated from T_1T for ^{8}B in platinum metal. The platinum stopper was attached to the bottom of a liquid-helium dewar and was surrounded with an rf coil. The feeder line to the rf coil was installed through liquid helium. The platinum stopper and the rf coil were enclosed in two kinds of thermal shields of 4.2 K and 77 K. The recoil collimator which was made of copper was also cooled to 77 K in order to reduce thermal radiation into the stopper. Four litters of liquid helium were enough to measure the resonances during about 20 hours.

The anisotropy of β emission due to the nuclear polarization was detected by two pairs of Si detectors, which were located one side and the other side of the reaction plane. The change of asymmetry in the β-ray emission was detected by the β-ray counting-rate ratios with and without the rf-field; the asymmetry change ΔA was defined by

$$\Delta A=\left\{\left(\frac{Y_{\mathrm{I}}}{Y_{\mathrm{II}}}\right)_{\mathrm{on}}\Big/\left(\frac{Y_{\mathrm{I}}}{Y_{\mathrm{II}}}\right)_{\mathrm{off}}\right\}-1\ ,$$

where Y_{I} and Y_{II} are the counting-rates in each counter.

The deuteron beam was periodically chopped into 0.7 sec durations in every 4 sec for the bombardment and following 1.5 sec durations were used for the counting. The rest durations of 1.8 sec were used to detect the background, and the background counts were normalized in times and subtracted from the counts in the first section.

In the first step of the resonance experiment, the search for resonance was carried out by use of the adiabatic passage with 4% sweep in rf frequency and an asymmetry change could be detected in NMR. The sweep time of rf field was 100 msec and the effective rf field H_1 was about 2G. After finding the resonance, the incident energy was changed to search for a better condition. Successive measurements with 2% and 0.4% sweep range in rf-field were made at the deuteron energy of 3.7 MeV and 4.1 MeV. About $5\sim8\%$ of asymmetry change was observed in these experiments.

The resonances of ^{41}Sc observed in the present measurements are shown in Fig. 2 and summarized in Table I. In the figure, the abscissa is indicated in units of percent change in the magnetic field for the comparison by the different sweep range. This observed resonance shape was as expected by the adiabatic passage method. The best-fit curves for the resonances were determined using the theoretical expectation and drawn by the solid line in the figure. The parameter of line width to fit the observed curve was comparable to the width due to the applied H_1 field ($\sim$2G). Thus the natural width of the resonance could be smaller than the width due to H_1 and in agreement with the expected dipolar broadening ($\sim$1 kHz). Thus no significant disturbing process was found to be accompanied with the recoil implantation process at 4.2 K.

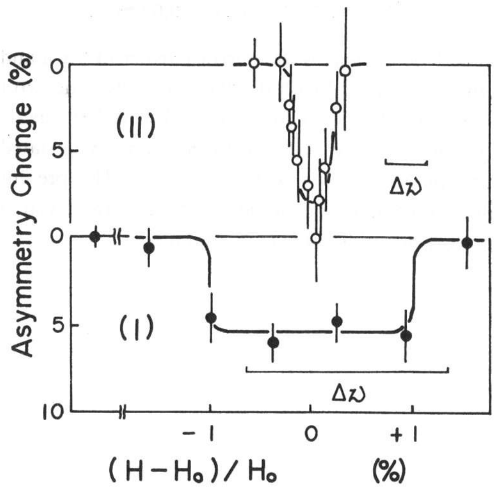

Fig. 2. Nuclear magnetic resonances of ^{41}Sc in Pt at 4.2 K by the adiabatic passage method.

The magnetic moment of ^{41}Sc in platinum metal was found to be

$$\mu_{\mathrm{uncorrected}}(^{41}\mathrm{Sc},\ 7/2^-)=5.4216\pm0.0026\ \mathrm{nm}\ .$$

This value is not corrected by the Knight shift and the diamagnetism. The correction factor for diamagnetism was referred to the calculated values for the atomic state by Dickinson; 1.51×10^{-3}. The inhomogeneity of magnetic field was found experimentally to be less than 10^{-4}. The main uncertainty arised from unknown Knight shift for Sc in platinum metal, which was considered to be at most that for Sc in scandium metal; 0.26%. Thus the present value of magnetic moment was determined to be

Table I. Magnetic Moment of ^{41}Sc.

		Run I	Run II
H_0	in unit of proton res. freq. (MHz)	31.065 (25)	30.760 (18)
Rf	sweep range (MHz)	8.5238～8.7014	8.5107～8.5444
Rf	center freq. (MHz)	8.6126	8.5276
μ	(nm)	5.4256 (44)	5.4195 (32)
μ	mean value (nm)	5.4216 (26)	
μ	corrected* (nm)	5.4298 (26)	

* Diamagnetism for scandium was corrected ($1.51\cdot10^{-3}$) .

$$\mu(^{41}\mathrm{Sc}, 7/2^-) = 5.43 \pm 0.02 \text{ nm} .$$

The ^{41}Sc nucleus is the mirror partner of ^{41}Ca and both are composed with the ^{40}Ca core plus one extra nucleon in the $f_{7/2}$ orbit. The observed magnetic moment of ^{41}Ca (-1.59 nm) is appreciably deviated from the Schmidt value (-1.91 nm). The present value on the magnetic moment of ^{41}Sc is also deviated from the Schmidt value ($+5.79$ nm).

References

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3) S. Kohzuki and K. Asayama: J. Phys. Soc. Japan **32** (1972) 1237.