Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985
J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 1086-1087

8.19 Nuclear Polarization of Short-Lived β Emitters ^{8}Li, ^{12}B and ^{27}Si Created by the Tilted Foil Technique

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For systematic studies on nuclear strucptures of light mirror nuclei (A<40), as well as on structure of weak nucleon currents, it has been indispensable to determine mirror magnetic moments and the related decay rates. One of a mirror pair among them, however, is always an unstable nucleus. For determination of magnetic moment of emitters, an NMR method applicable to unstable nuclei has been developed in our laboratory[1]. In the first step of the NMR detection, it is of great importance to prepare β emitters whose nuclear spins are polarized. Nuclear polarization phenomena have been so far used to obtain polarized β emitters in a series of the NMR measurements done by our group. Recently, a new technique to create nuclear polarization of heavy-ions has been developed in the field of atomic physics; the tilted foil technique[2]. The technique consists of the two steps; first, to create atomic polarization by passage of an ion beam through a tilted foil surface, second, to transfer the atomic polarization to a nucleus by means of the hyperfine interactions during flight in free space. Application of the technique to the NMR method has already started for redetermination of known magnetic moment of emitter ^{27}Si ($I^{\pi} = 5/2^{+}$, $T_{1/2} = 4.1$ s)[3]. Usefulness and effectiveness of the technique were also demonstrated for other β emitters, ^{8}Li ($I^{\pi}= 2^{+}$, $T_{1/2} = 0.84$ s) and ^{12}B ($I^{\pi}= 1^{+}{}_{1/2} = 20$ ms), whose magnetic moments have been already known.

The experimental setup of the present NMR measurements is shown in Fig. 1. The system consists mainly of two parts; the first is an assembly of a target and a multi-tilted foil array[4] used for production of polarized β emitters, and the second is an on-line NMR system which makes use of asymmetric β decay from polarized nuclei. In the ^{27}Si experiment, the ^{27}Si nuclei were produced through the $^{27}Al(p,n)^{27}Si$ reactions. The proton beam of $E_p = 11{\sim}15$ Mev was prepared by the AVF cyclotron at RCNP, Osaka University. Three carbon foils (10 μg/cm^2) were tilted and set in sequence after an Al target foil (400 μg/cm^2). These foils were all tilted 60 relative to the beam direction. By final interactions with each tilted foil surface, silicon atoms were polarized. During flight in a magnetic field around the foils weaker than 10 Oe, the atomic polarization created was transferred to the ^{27}Si nuclei and piled up to a saturated value by multi-tilted foils. The polarized ^{27}Si nuclei were implanted into a Pt foil (~5 μm thick) to maintain the induced nuclear polarization during nuclear lifetime. In order to increase the nuclear spin-lattice-relaxation time T_1 of ^{27}Si in Pt, the Pt foil was cooled down at 20 K by use of a cryogenic refrigerator. An external magnetic field H_0 of 2 kOe was applied parallel to the nuclear polarization to decouple possible depolarization effects in the metal. The induced nuclear polarization for ^{27}Si was determined by measuring β-ray asymmetry by two sets of plastic scintillation counters set above and below the Pt foil. By applying an rf magnetic field perpendicular to the static field, the nuclear spins of ^{27}Si was reversed by the adiabatic fast passage of the NMR method.

In the first stage of the measurement, an appreciable amount of the NMR effect was found to be equivalent to the g-factor of ^{27}Si, $0.26<g<0.39$. The value of T_1 for ^{27}Si in Pt at 20 K was found to be $T_1 = (3.4\pm0.8)$ s. By correcting the observed β-decay asymmetry with the observed T_1, the nuclear polarization P of ^{27}Si was deduced to be $P=(2.0\pm0.8)$ %. For more precise g-factor of ^{27}Si, the further measurements are now in progress.

For demonstration of the effectiveness of the tilted foil technique, nuclear polarization of ^{8}Li and ^{12}B were created by use of the similar experimental setup of ^{27}Si. In the case of ^{8}Li, nuclear polarization of ^{8}Li has not been reported so far in nuclear reactions induced by unpolarized beam. The polarized ^{8}Li nuclei could only be prepared by the polarized neutron-capture reaction[5] and the polarization transfer process initiated by fast polarized beams[6]. Presently the nuclear polarization of ^{8}Li was induced by ten sheets of tilted foils and determined by the NMR method with its known g-factor. From the observed NMR spectrum of ^{8}Li shown in Fig. 2, the induced nuclear polarization of ^{8}Li was found to be (1.23±0.29) %, which seems quite consistent for lithium ions whose atomic states are mainly S-states in the present experimental conditions.

The nuclear polarization of ^{12}B has already been confirmed by the previous experiment by the tilted foil technique[7]. In the present experiment, the nuclear polarization was measured for various atomic states of boron atoms. It was found that the nuclear polarization of ^{12}B showed a tendency to increase as the atomic states of boron changed from S-state to P-state. This fact is consistent with the recent experiment by Winter et al.[8] which disclosed the atomic state dependence of induced nuclear polarization.

As a conclusion, the tilted foil technique has appeared quite effective for NMR experiments for short-lived β emitters.

Present work was supported in part by Yamada Science Foundation, Grant-in-Aid for Scientific Research, and Grant-in-Aid for Special Project Research on Interaction of Ion Beams with Solids from Ministry of Education, Science and Culture.

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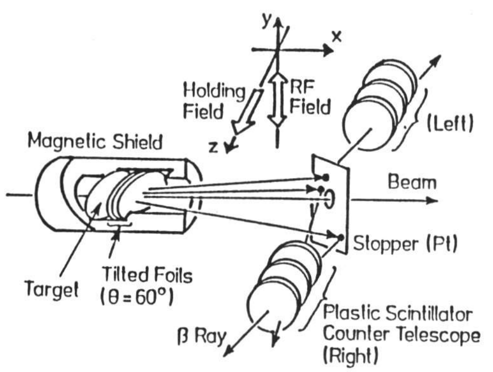

Fig. 1. Schematic view of the present experimental setup.

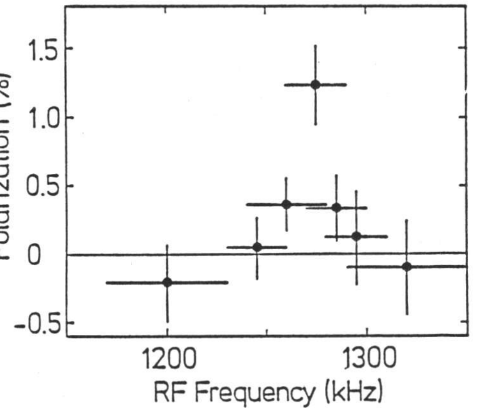

Fig. 2. The NMR spectrum of ^{8}Li obtained by use of the tilted foil technique.