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8.20 Nuclear Spin Polarization of ^{27}Al Produced by Tilted-Foil Method and Determination of the Polarization by Coulomb Excitation

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Recently production of polarized heavy ions using tilted-foil method has been studied in the fields of atomic physics[1] and nuclear physics.[2] Here we report a new method[3] in determining nuclear spin polarization produced by tilted-foil method, utilizing left-right asymmetry of scattered particles in the projectile Coulomb excitation. This method can be particularly useful for ions with relatively high energies, i.e. a few MeV/nucleon, where the cross section for the Coulomb excitation becomes large, while other conventional methods become difficult to apply. The tilted-foil method seems to be promising to produce polarized heavy ions even in deeply ionized states of heavy element in such an energy region. we have, therefore, planned to study the method systematically. This is the report of the first trial.

In the E2 Coulomb excitation process, the predominant contribution comes from the component with the magnetic substate of M=+2, being Z $\vec{k}_f \times \vec{k}_i$, where $\vec{k}_f$ and $\vec{k}_i$ are the wave vectors of scattered and incident ions, respectively. In the cace of polarized projectile the angular distribution of Coulomb excitation, governed by the vector coupling between the projectile spin and the transferred angular momentum (see fig. 1), give rise to left-right asymmetry which is proportional to the projectile polarization. In order to separate Coulomb excitation events from intense elastic events and further more in order to identify the channel of Coulomb excitation, scattered particles are measured in coincidence with the de-excitation gamma-ray emitted from Coulomb excitation levels of projectile.

In the present experiment, ^{27}Al ions accelerated up to of 35.5MeV by RIKEN heavy ion linear accelerator (RILAC) was used. The experimental setup is schematically shown in fig. 2. A tilted multifoil array acts as a polarizer of incident heavy ions. The multifoil array were mounted up to five carbon foils of $6\mu g/cm^2$. The tilt angle was either $\theta(\hat{n},\vec{k}_i)=+60^\circ$ ($\uparrow$) or $\theta(\hat{n},\vec{k}_i)=-60^\circ$ ($\downarrow$), where $\hat{n}$ is the normal vector of the tilted foils. The experimental conditions were chosen by optimizing the balance among i) a larger analyzing power of polarization, ii) a larger cross section for the Coulomb excitation and iii) a larger ratio of the Coulomb excitation cross section to the elastic scattering cross section. The third factor, which is 5×10^{-4} in the present experimnt, is particularly important for the efficiency of the method since the counting rate of the particle counter is limited primarily by the number of elastic scattering. Carbon target in thickness of $200\mu g/cm^2$ was used. A pair of Si detectors placed at the angle $\theta_{lab}=\pm(40^\circ\pm5^\circ)$ symmetrically with respect to the beam axis to detect left-right asymmetry of recoil cabon as substitute for scattered ^{27}Al, where the detection angles correspond to $\theta_{C.M.}=\pm(100^\circ\pm10^\circ)$ scattering of ^{27}Al projectile. Gamma-ray detectors covered a large solid angle of 2.2sr. Coulomb excitation of $5/2^+$(g.s.) $\to 1/2^+$ (0.84MeV) in ^{27}Al projectile and that of $5/2^+$(g.s.)$\to$ $3/2^+$ (1.01MeV) are well separated from intense elastic events.

In order to minimizing systematic errors we measured the double ratio ρ^2 (see below) for determination of left-right asymmetry of the Coulomb excitation by the polarized projectile after passing through the tilted foils. The tilt angle of the foils was automatically driven between +60° ($\uparrow$) and -60° ($\downarrow$) after the accumulation of a preset number of count. Double ratio is related to left-right asymmetry (A) as follows.

$$A = \frac{1-\rho}{1+\rho} \quad (1), \qquad \text{where} \qquad \rho = \sqrt{\frac{N^L_\uparrow \; N^R_\downarrow}{N^L_\downarrow \; N^R_\uparrow}} \quad (2)$$

Here $N^L_\uparrow, N^R_\uparrow, N^L_\downarrow$ and $N^R_\downarrow$ are recoil carbon counts in right (R) or left (L) with the polarizig foil tilted up ($\uparrow$) or down ($\downarrow$), respectively. Table 1. summarizes the present result of left-right asymmetry (A). Asymmetries due to the measuring system were estimated to be negligibly small using the random coincidence, as shown in Table 1. Left-right asymmetry (A) in the E2 Coulomb excitation cross section of I=5/2 polarized beam is written as

$$A = \frac{\sigma^L - \sigma^R}{\sigma^L + \sigma^R} = \frac{\sum_{odd} t_{k0}\cdot g_k}{\sum_{even} t_{k0}\cdot g_k} = \frac{t_{10}\cdot g_1 + t_{30}\cdot g_3}{g_0 + t_{20}\cdot g_2 + t_{40}\cdot g_4} \qquad (3)$$

where t_{k0} is statistical tensor of the incident I=5/2 beam and g_k is relative intensity with rank k. In eq. (3) $t_{20}g_k$ and $t_{40}g_k$ is small as compared with g_0. Asymmetry (A) is represented by a linear conbination of P_1 (polarization) and P_3 (tensor polarization with rank 3). P_1 and P_3 could be resolved from the two kinds of measurement; one is the $5/2^+ \rightarrow 1/2^+$ and another $5/2^+ \rightarrow 3/2^+$. Our result shows an enhancement of P_1 from the value P_1=1.5%±0.9% with two tilted foils to a P_1=2.3%±0.6% with five tilted foils.

In conclusion, the present investigation has demonstrated that i) the left-right asymmetry in the projectile Coulomb excitation is effective to determine the nuclear spin polarization and ii) a finite nuclear spin polarization can be produced by the tilted foil method in the relatively high energy region, i.e. a few MeV per nucleon, where incident projectiles after passing through foils are deeply ionized ($Z\simeq 9.2$).

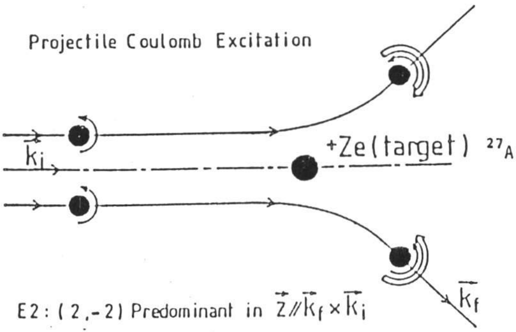

Fig. 1. Schematic Figure of an angular momentum transfer in the E2 transition.

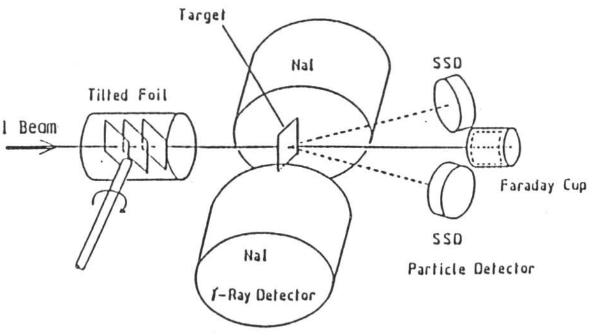

Fig. 2. Schematic figure of the nuclear spin polarization measurement system.

Table 1. Summary of the left-right asymmetry (A) in the present measurement.

Number of foils	$5/2^+ \rightarrow 1/2^+$	$5/2^+ \rightarrow 3/2^+$	System asymmetry
2	+1.3%±1.0%	+1.6%±1.1%	-0.3%±0.5%
5	+1.5%±0.7%	+2.5%±0.8%	-0.07%±0.20%

Refereences

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