Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985
J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 1042–1043

7.12 Measurement of the atomic polarization and nuclear magnetic moment of the 2_1^+ state in ^{22}Ne with a tilted-foil method

M. Adachi, N. Yamada, M. Taya, T. Kohno, A. Makishima, T. Suzuki, S. Fukuda, M. Fukuda, T. Nagafuchi and H. Taketani

Department of Applied Physics, Tokyo Institute of Technology
Oh-okayama, Meguro, Tokyo 152, Japan

It has been discovered by Berry et al.[1] in 1974 that an orbital angular momentum of atomic beam after passing through a tilted foil is polarized to the direction of $\vec{n} \times \vec{V}$, where $\vec{n}$ is the normal to the foil plane and $\vec{V}$ is the direction of the beam velocity. This phenomenon provides a new tool for measuring g-factors of short-lived (ps) nuclear states[2] or for studying the atomic polarization[3,4] by detecting a rotation of the perturbed angular correlation (distribution) of de-exciting γ-rays. The rotation is caused by the polarization of electronic configuration which interacts with a nuclear state via the hyperfine interaction. At present, however, the g-factor measurements with a tilted foil are scarce and the applicability of the method has not been well established. In the present study the 2_1^+ state of ^{22}Ne, whose g-factor and meanlife are known to be $g=0.326\pm0.012$ and $\tau=5.2\pm0.3$ ps[5], has been applied to the tilted-foil method and the atomic polarization has been deduced using the $g\tau$ value.

The 2_1^+ state of ^{22}Ne was populated via the ^{19}F(α,pγ)^{22}Ne reaction using He^{2+} beam of 8 MeV from the TIT Van de Graaff. The targets were made of 55 μg/cm^2-thick LiF evaporated on 20 μg/cm^2-thick carbon foil or thick Cu backing. The latter was used to measure the unperturbed angular correlation. The 1.27 MeV γ-rays ($2^+ \rightarrow 0^+$ in ^{22}Ne) in coincidence with outgoing protons were detected with four 7.5-cm φ x 7.5-cm long NaI(Tl) detectors placed in four-detector arrangement[3]: detectors at ±65° and ±115° to the beam direction in the present experiment. Protons emitted backward were detected with a 500 μm-thick annular surface-barrier detector. At the angle 60° between the normal to the target and the beam direction, a precession angle $\Delta\psi$ due to the tilting of the target foil was measured to be 1.61±0.59 mrad.

The effect of atomic polarization produced in the tilted foil geometry on the angular correlation of nuclear decay γ-ray is well investigated by Niv et al.[6] A time integrated perturbed angular correlation is given by

$$W(\Theta) = \sum A_k [\overline{G_k} P_k(\cos\Theta) + \overline{H_k} P_k^1(\cos\Theta)]$$

where A_k are unperturbed correlation coefficients and P_k and P_k^1 are the Legendre and associated Legendre polynomials. $\overline{G_k}$ and $\overline{H_k}$ are attenuation and precession coefficients averaged over the ionic ensemble and are given by,

$$\overline{G_k} = \sum_{q,L,S,J} \pi(q,L,S,J) G_k(L,S,J),$$

$$\overline{H_k} = \sum_{q,L,S,J} \pi(q,L,S,J) H_k(L,S,J),$$

$$G_k(L,S,J) = \frac{1}{2J+1} \sum_{FF'} (2F+1)(2F'+1) \begin{Bmatrix} F & F' & k \\ I & I & J \end{Bmatrix}^2 \frac{1}{1+(\omega_{FF'}\tau)^2},$$

$$H_k(L,S,J) = \frac{-3p\cos(J,L)}{\sqrt{J(J+1)}\; k(k+1)\tilde{\omega}\tau}(1-G_k)$$

; $\pi(q,L,S,J)$ is the population probability of the term (L,S,J) with charge q, I and J are the angular momenta of the nucleus and electrons, $\vec{F}=\vec{I}+\vec{J}$ and $\vec{J}=\vec{S}+\vec{L}$, $\omega_{FF'}=1/2[F(F+1)-F'(F'+1)]\tilde{\omega}$, $\tilde{\omega}=g\mu_N\overline{H(0)}/\hbar J$ where $\overline{H(0)}$ is the mean magnetic field at the nucleus generated by the electron configuration, g and μ_N are the g-factor and the nuclear magneton, τ is the meanlife of the nuclear level and $p=\langle L_x\rangle/\sqrt{L(L+1)}$ $(L\neq 0)$ is the polarization fraction. In order to deduce the fraction p, one has to know the electronic configuration of Ne ions recoiling into vacuum at $v/c=1.4\pm0.2$ %. The velocity was measured from the Doppler shift of the 1.27 MeV γ-rays with a Ge(Li) detector. With adopting an intermediate ionization model[7], the electronic configurations of $(1s)^2(2s)^m(2p)^{8-m-q}$ (m=0,1,2) were taken into account for the present analysis. An equilibrium distribution[8] was used for the charge distribution and the population probabilities, $\pi(q,L,S,J)$, were assumed to be proportional to the statistical weight of 2J+1. The contribution of 2s electrons to the $\overline{H(0)}$ was estimated from the Hartree-Fock calculations for O[7] and Na[9] ions. The contribution of 2p electrons was calculated with an energy sum method[10]. A relation, $\Delta\psi/p$ vs. $g\tau$, obtained with the analyzing procedure mentioned above is shown in Fig. 1. Using the experimental value of $g\tau=1.70\pm0.12$ ps[5] and $\Delta\psi=1.61\pm0.59$ mrad, obtained in this experiment, the p is deduced to be 0.052 ± 0.019 for ^{22}Ne ions recoiling into vacuum at v/c=1.4 %. This value is consistent with other ions at nearly the same recoiling velocity: ^{16}O (p=0.05 and v/c=1.1 %)[4] and ^{40}Ca ($p=0.077\pm0.018$ and v/c=1.2 %)[2]. The value $|g\tau|=2.4\pm0.7$ ps, which is consistent with the previous one[5] within the experimental error, was also obtained from the attenuation coefficient $\overline{G_k}$ determined in the present experiment. The sign of the g-factor was determined to be positive from the direction of rotation of the perturbed angular correlation.

The tilted-foil method is a simple one to measure the g-factors, including their sign, of very short-lived (ps) nuclear states by only tilting the target foil. It is also applicable to measure the atomic polarization when the $g\tau$ value is known.

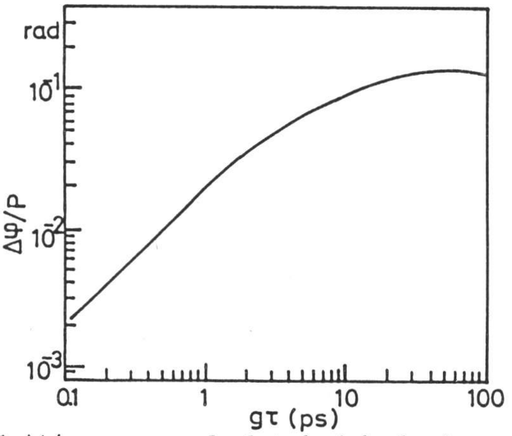

Fig. 1 $\Delta\psi/p$ vs. $g\tau$ calculated with the intermediate ionization model for Ne ions at v/c=1.4 %.

References

1) H. G. Berry, L. J. Curtis, D. G. Ellis and R. M. Schectmann: Phys. Rev. Lett. 32 (1974) 751.
2) Y. Niv, M. Hass, A. Zemel and G. Goldring: Phys. Rev. Lett. 43 (1979) 326.
3) M. Hass, J. M. Brennan, H. T. King, T. K. Saylor and R. Kalish: Phys. Rev. Lett. 38 (1977) 218.
4) G. Goldring, Y. Niv, Y. Wolfson and A. Zemel: Phys. Rev. Lett. 38 (1977) 221.
5) R. E. Horstman, J. L. Eberhardt, P. C. Zalm, H. A. Doubt and G. van Middelkoop: Nucl. Phys. A275 (1977) 237.
6) Y. Niv, M. Hass and A. Zemel: Hyp. Int. 8 (1980) 19.
7) C. Broude, M. B. Goldberg, G. Goldring, M. Hass, M. J. Renan, B. Sharon, Z. Shkedi and D. F. H. Start: Nucl. Phys. A215 (1973) 617.
8) A. B. Wittkower and H. D. Betz: Atomic Data 5 (1973) 113.
9) F. Beck, Y. Dar, M. Forterre and J. P. Vivien: Phys. Rev. C13 (1976) 895.
10) H. Kopfermann: Nuclear Moments (Academic Press Inc., 1958)