Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985
J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 1148-1149

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The Low Energy Proton Polarimeter for the Polarized H^- Beam Source at the Brookhaven AGS*

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A new type of proton polarimeter has been developed and tested with the 20 keV polarized H^- beam source [1] at the Brookhaven AGS. The instrument, which is depicted schematically in Fig.1, is based on beam foil spectroscopy and involves the measurement of circular polarization of Lyman-α light. The method has previously been applied only to heavier nuclei with photon detection at longer wavelengths [2] [3].

The principle of the method is the following. The polarized hydrogen ion beam passes at low energy (10 keV to 100 keV) through a thin carbon foil (5μg/cm²). Any electrons associated with the projectiles are stripped upon entering the foil. Therefore it does not matter whether H^+ or H^- beams are being used. The foil is traversed within 10^{-14}s, which is short compared to all hyperfine periods. The nuclear spin orientation is therefore not affected by the passage through the foil. When the protons exit from the foil, a fraction of them will pick up an electron and emerge as neutral hydrogen atoms in the 2P state. As the excited atoms move away from the foil, a transfer of angular momentum (orientation) occurs via hyperfine interaction from the nuclear spin to the electron orbit, which will manifest itself through circular polarization of the Lyman-α photon decay. Maximum circular polarization will be observed for photons emitted along the spin quantization axis, and the extent of the circular polarization will be a direct measure of the original nuclear polarization.

The circular polarization Stokes parameter can be expressed in the form $S/I = P \cdot A(t)$, where P is the beam polarization, and A(z) or A(t) is the analysing power of the process at the distance z from the foil (or time of flight $t = z/v$), which is the degree of circular polarization obtained in the case of complete (P=1) beam polarization. Using the formalism developed by Ellis [4], we reach the following result

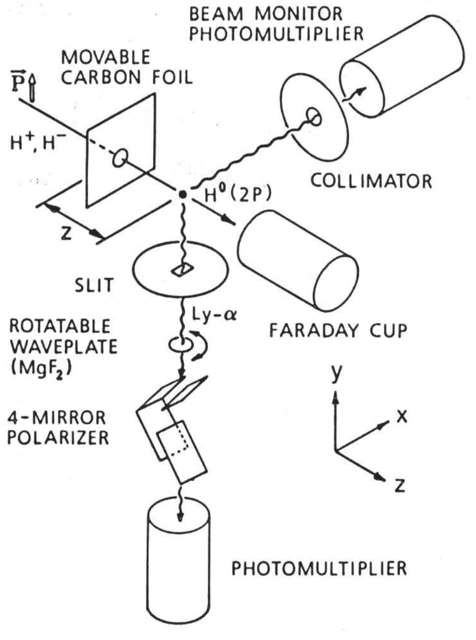

Fig. 1. Beam Foil Proton Polarimeter

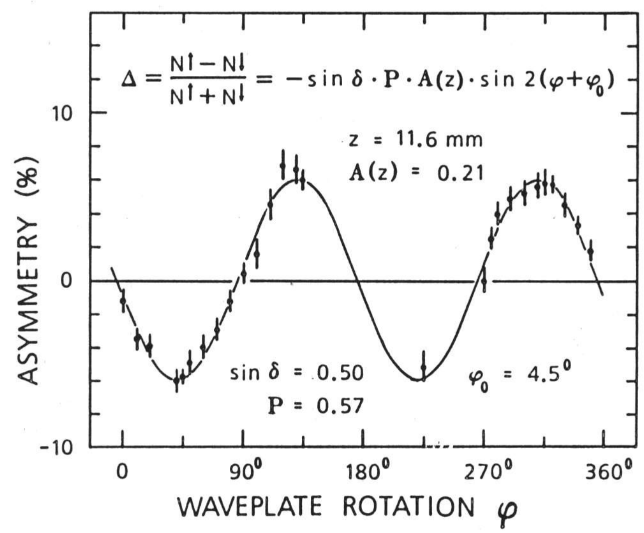

Fig. 2. Measured asymmetry of Lyman-α photon counts vs. waveplate rotation. The curve is a fit of the given functional form, from which a beam polarization of P = 0.57 was deduced.

* Work supported in part by U.S. Department of Energy
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$$A\ (t) = (5/24)\cdot(1-\cos\omega_{3/2}t) + (1/6)\cdot(1-\cos\omega_{1/2}t) \quad (1)$$

for the Lyman-α decay of 2P states originating at the foil at t=0, where $\omega_{1/2}=2\pi\cdot 59$MHz and $\omega_{3/2}=2\pi\cdot 24$MHz are the hyperfine splittings of the J=1/2 and J=3/2 levels. A more exact version § of (1), allowing for alignment of the 2P state [6], is only slightly different. Much more significant, however, is the effect of cascading from higher excited states, with 3D being the most important. We obtain for the total intensity $I = I_{2P} + I_{3D}$ and for the cascade modified analysing power A the following expressions

$$I\ (t) = C\ \exp(-\gamma_2 t)\ \left\{ 1 + \left[B\gamma_3/(\gamma_2-\gamma_3)\right]\cdot\left[\exp(\gamma_2-\gamma_3)t - 1\right] \right\} \quad (2)$$

$$A\ (t) = (C/I(t))\cdot \left\{ \tilde{A}(t)\exp(-\gamma_2 t) + B\gamma_3 \int_0^t \tilde{A}(t-\alpha)\exp(-\gamma_3\alpha)\exp(-\gamma_2(t-\alpha))d\alpha \right\} \quad (3)$$

where C is a constant, $1/\gamma_2$ is the 2P lifetime (1.6ns), $1/\gamma_3$ is the 3D lifetime (15.6ns), B is the 3D/2P population ratio at the foil (t=0), and the original analysing power from Equ.(1) appears now as $\tilde{A}(t)$ in Equ.(3).

The principal components of the instrument are shown in Fig.1. The carbon foil target can be moved along the beam axis. The UV-polarimeter has a 3 mm slit that samples a slice of the beam, followed by a rotatable MgF_2 waveplate [7] and a Brewster angle type four-mirror polarizer [7] [8], both obtained from NASA, and a PM with CsI cathode and MgF_2 window. A second PM serves as intensity monitor. The waveplate available to us, with a circular analysing power of $\sin\delta = 0.50\pm0.10$ at Ly-α, was not ideal, but still useful.

The beam foil polarimeter has been tested with the 20 keV polarized H^- source [1] at BNL, which delivered a pulsed beam of up to 5×10^{10} H^-/300μs pulse at ~1 pps. Photons were counted in two sets of scalers, flipping either the waveplate (±45°) or the beam polarization (↑,↓).

There is clear evidence of circular polarization (Fig.2), and the observed dependence on foil position (Fig.3) is well described by the cascade modified theory.

The magnitude of the polarization of the H^- beam, as determined from the size of our measured asymmetries, was:

$P^{\uparrow} = 0.45 \pm 0.09$; $P^{mean} = 0.57 \pm 0.11$
$P^{\downarrow} = 0.69 \pm 0.14$; $P^{\uparrow}/P^{\downarrow} = 0.65 \pm 0.06$

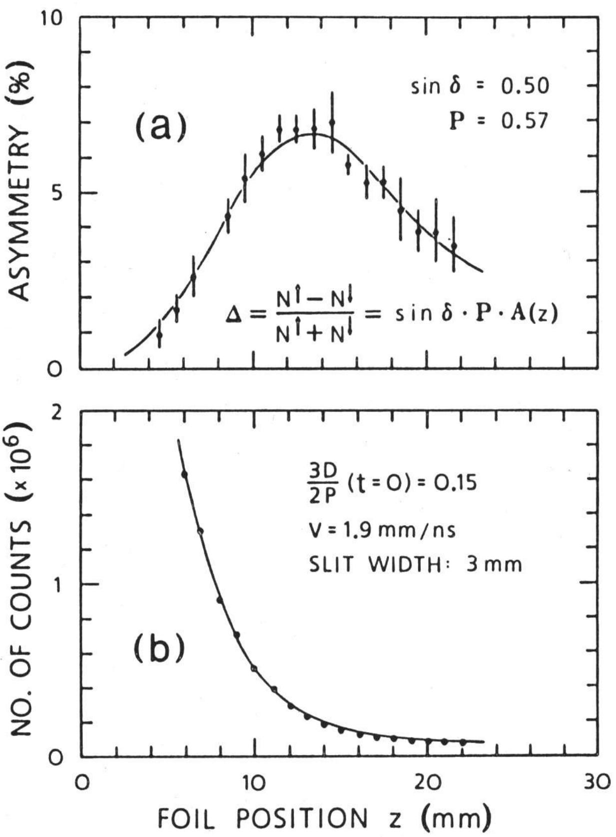

Fig. 3. Measured asymmetry of Lyman-α photon counts and intensity vs. foil position. The theoretical curves include cascading from the 3D state according to Equ. (2) and Equ. (3).

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§ $A(t) = \left[(10+2A_o^{col})(1-\cos\omega_{3/2}t)+8(1-\cos\omega_{1/2}t)\right] / \left[48-A_o^{col}(5+3\cos\omega_{3/2}t)\right]$, where A_o^{col} is the Fano-Maček alignment parameter (Ref.5); for H(2P) alignment data see Ref. 6.