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THE LOW ENERGY PROTON POLARIMETER FOR THE POLARIZED H⁻ BEAM SOURCE AT THE BROOKHAVEN AGS*

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ABSTRACT

A proton polarimeter suitable for spin polarized H^+ and H^- ion beams of low energy (10 keV to 100 keV) has been developed and tested with the 20 keV polarized H^- beam source at the Brookhaven AGS. Following the production of neutral hydrogen atoms in the 2P state by collision with a thin carbon foil, the beam polarization is measured by detecting the circular polarization of the resultant Lyman-α decay photons.

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].

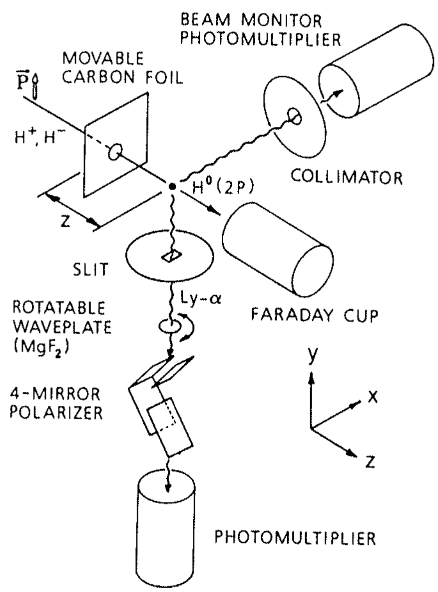

Fig. 1. Beam-Foil Proton Polarimeter

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 ($5 \mu g/cm^2$). 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 proton 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 proton 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

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spin quantization axis, and the extent of the circular polarization will be a direct measure of the original proton 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 analyzing 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

$$A(t) = (5/24) \cdot (1-\cos\omega_{3/2}t) + (1/6) \cdot (1-\cos\omega_{1/2}t) \qquad (1)$$

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 eq.(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. In this regard the 3D state, with a 3D→2P lifetime of 15.6 nsec, is of primary concern. We obtain for the total intensity $I = I_{2P} + I_{3D}$ and for the cascade modified analyzing power A the following expressions

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

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

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

The theoretical Lyman-α photon intensity and analyzing power according to eq. (2) and eq. (3) are plotted in Fig. 2 for a cascading parameter B=0.15 that follows from measurements of Bukow et al.[7]. For a realistic comparison with measurements, the energy loss of the projectiles in the foil, the time resolution corresponding to the slit width and the geometrical acceptance of the optical polarimeter have to be considered.

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 [8] and a Brewster angle type four-mirror polarizer [8][9], both obtained from NASA, and a photomultiplier with CsI cathode and MgF_2 window. A second photomultiplier serves as intensity monitor. The circular analyzing power of the waveplate now used is $\sin\delta = 1.00 \pm 0.04$. This is a considerable improvement over the earliest operation of the instrument ($\sin\delta = 0.5 \pm 0.1$) reported at the Osaka Conference [10].

The beam-foil polarimeter has been tested with the 20 keV polarized H^- source PONI-1 at BNL [1][11], which delivered a pulsed beam of up to 5×10^{10} H^- per 300μs pulse at ~1 pps. Photons were counted in two sets of scalers, flipping either the waveplate (±45°) or the beam polarization (↑,↓).

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§ $A(t) = [(10+2A_0^{col})(1-\cos\omega_{3/2}t)+8(1-\cos\omega_{1/2}t)]/[48-A_0^{col}(5+3\cos\omega_{3/2}t)]$,

where A_0^{col} is the Fano-Macek alignment parameter (Ref.[5]); for H(2P) alignment data see Ref.[6].

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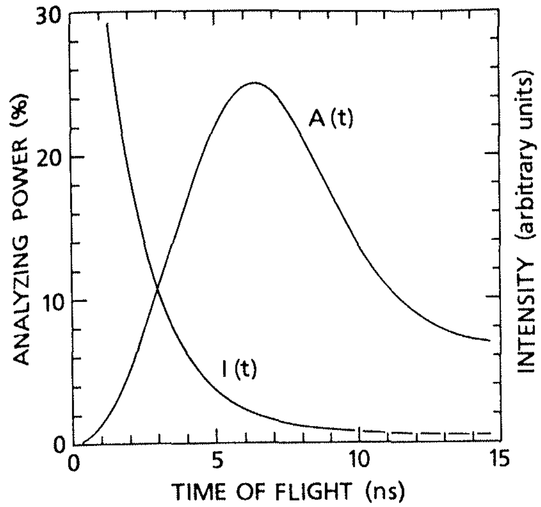

Fig.2. Theoretical analyzing power A(t) and Ly-α photon intensity I(t). The curves include modifications due to cascading from the 3D state(15%) according to eq.(2) and eq.(3).

The observed dependence of the Lyman-α photon intensity and circular polarization on foil position (Fig. 3) are well described by the cascade modified theory. The measured asymmetries are now larger by more than a factor of two compared to earlier data reported at the Osaka Conference [10]. This is mainly due to the better optics in the polarimeter. There has also been some work on the rf transition regions in the polarized H^0-stage of the source [11] that has resulted in a much improved weak field polarization. The magnitude of the polarization of the H^- beam, as determined from the size of our measured asymmetries, was:

(Weak Field Pol.:) P↑ = 0.81
(Strong Field Pol.:) P↓ = 0.67

The statistical error is about ± 0.01. The systematic error is estimated to be around ± 0.05, which includes the uncertainties of the cascading factor, the speed of particles after the foil and the analyzing power of the optics.

Fig.4 and Fig.5 show some examples of the measured asymmetries as a function of various parameter settings in the source. It indicates that this polarimeter can be used as a tuning device to maximize beam polarization.

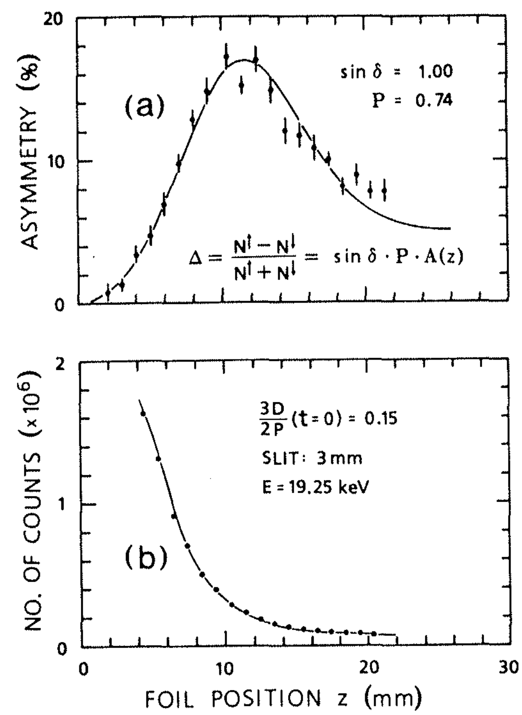

Fig.3. Measured circular polarization of Ly-α photons and intensity vs. foil position. The curves are fits to the functional forms given in Fig.2, with instrumental acceptance and resolution included, from which an average proton polarization of P=0.74 was deduced.

The analyzing power of this polarimeter will not depend on beam energy, because the cascading factor is believed to be reasonably constant in the energy range of interest [7]. This has been verified in a limited range between 10 keV and 20 keV. Counting rate considerations favor the energy range from 10 keV to 100 keV. At higher energies the 2P production cross section drops rapidly [12]. The beam-foil polarimeter is intrinsically simple and has the great advantage that it can operate at typical source energies without further acceleration.

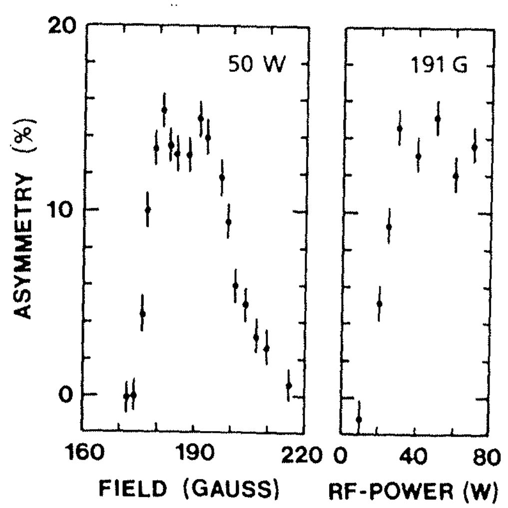

Fig.4. Tuning of the high frequency (1.49 GHz) rf transition region in the polarized H^0-stage of the source for maximum P↓ polarization of the H^- beam. Correspondingly, there is a low-frequency (19.5 MHz) transition region for the P↑ polarization.

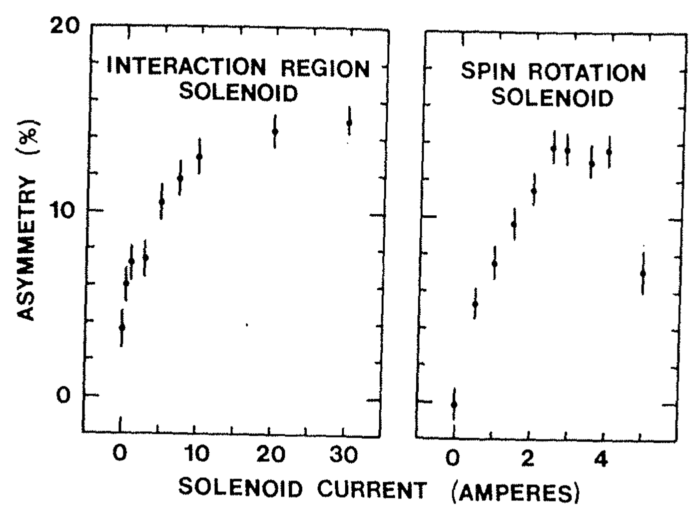

Fig.5. Tuning of solenoids in the source for maximum proton polarization. The magnetic field in the interaction region decouples the spin of the electron and proton. The spin rotation solenoid rotates the proton spin into an upright orientation.

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