Polarization of Lyman-α radiation from hydrogen $2p$ excited by tilted-foil interaction

H. Winter and H. W. Ortjohann
Institut für Kernphysik, Universität Münster, Wilhelm-Klemm-Strasse 9, D-4400 Münster, West Germany
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We have observed the polarization of Lyman-α radiation after the interaction of 70-keV protons with a thin tilted carbon foil. The circular polarization shows a sinusoidal dependence on the angle of tilt, whereas the components of linear polarization in the emitted radiation are found to be generally small. It is demonstrated that the polarization observed after the transmission through the foil at large angles of tilt extrapolates to the data obtained after the reflection of ions from the foil surface at grazing incidence.

The observation of elliptically polarized light emitted from atoms excited by a thin foil which is tilted with respect to the beam axis clearly shows that the final-state formation of atomic terms is localized at the exit surface of the solid.[1] Investigating the anisotropy in the population of magnetic sublevels of orbital angular momenta in excited terms of atoms and ions on the angle of tilt results in a dominant contribution of an orientation which monotonically increases with the tilt of the foil.[2-5] This orientation is probed by the circular polarization fraction $S/I=[I(\sigma^-)-I(\sigma^+)]/[I(\sigma^-)+I(\sigma^+)]$, where $I(\sigma^-)$ and $I(\sigma^+)$ denote the intensities of light with negative and positive helicity, respectively. Our study was motivated by the need to provide data with respect to the tilted-foil formation of a "simple" term in a one-electron atom, i.e., hydrogen $2p$. For the excitation of this term by a tilted foil, theoretical approaches are available[6,7] for which our data serve as a relevant testing case. In the experiments we used 70-keV H^+ ions which interact with a tilted carbon foil about 4 $\mu g/cm^2$ thick. The foils are mounted on a simple manipulator which allows a motion parallel and normal with respect to the beam axis and in addition a tilt by an angle α with respect to the beam axis. With the help of this manipulator excitation of atoms after transmission through the foil, but also after reflection from the foil surface without significant penetration into the bulk of the solid, is feasible. In Fig. 1 both geometries are sketched.

The polarization of the HI Lyman-α radiation emitted in the HI $1s$-$2p$ transition at $\lambda=121.6$ nm is observed perpendicular with respect to the beam axis by an analyzer consisting of MgF_2 components which are transparent at that wavelength. A commercially available MgF_2 quarter-wave plate (Fa. Halle Nachfl., Berlin) is rotated in front of a fixed linear polarizer which consists of a pile of four MgF_2 plates tilted at 60° with respect to the optical axis. Details with respect to this instrument and the evaluation of the specifications are given in Ref. 8. The retardation of the quarter-wave plate is found to be $\varepsilon=(92\pm2)°$, the degree of polarization of the polarizer $P=(85\pm1)\%$, and the transmission of both components was found to be about 14%. The Lyman-α radiation is detected by a VALVO X919BL channeltron where the spectral sensitivity of the detector ($\lambda<150$ nm) and the cutoff wavelength of MgF_2 at $\lambda=112$ nm (Ref. 9) provide the spectral isolation of the Lyman-α line in the spectrum of foil-excited hydrogen atoms. A sketch of the apparatus seen in the direction along the beam axis is shown in Fig. 2. The vacuum in the chamber is some 10^{-7} mbar.

The Stokes parameters[10] describing the state of polarization are determined by recording the count rates of the detector in dependence on fixed settings of the rotating quarter-wave plate. Figure 3 shows the results for various angles of tilt α. The data were taken with 70-keV H^+ ions at a current density of about 50 $\mu A/cm^2$. In contrast to previous measurements in beam-foil-excited He atoms,[11-13] a current density effect is not observed for the Lyman-α line. However, in the first few minutes of irradiation of a new foil the polarization (especially S/I) increases by about 10–20 % to reach a stable value. The data shown in the figure represent those stable conditions.

Main features of the data are generally small components of linearly polarized light ($M/I, C/I$), whereas the circular polarization fraction S/I increases in good approximation sinusoidally as indicated by the solid line which represents $S/I(\alpha)=0.22\sin\alpha$. Since the effective thickness of the foil increases by $1/\cos\alpha$, experiments at large angles of tilt are critical. According to Tolk *et al.*,[14] we achieve those angles by reflecting projectiles at the foil surface. In Fig. 3 we also show these data which correspond to $\alpha\approx88°$ and which can be nicely extrapolated from the foil transmission experiments.

The sine dependence of S/I and the results of the reflection-type experiment can be understood in terms of

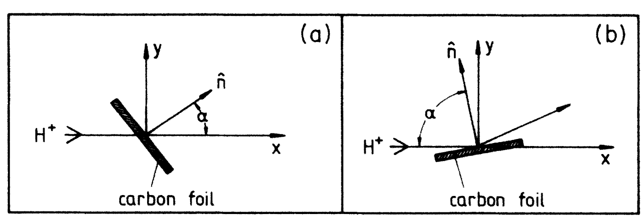

FIG. 1. Geometry of the tilted-foil experiment. (a) Experiment in transmission; (b) experiment in reflection.

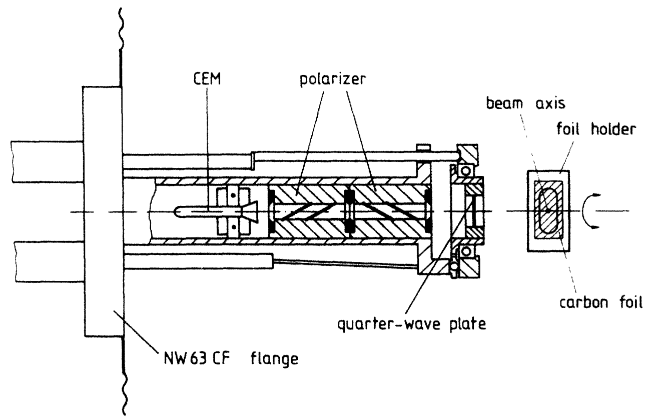

FIG. 2. Experimental setup as seen in direction along the beam axis.

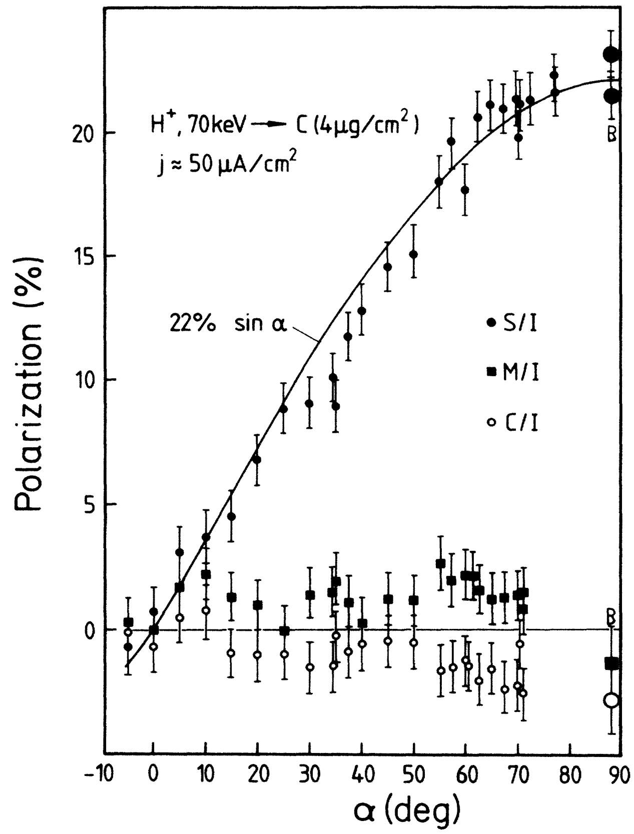

FIG. 3. Dependence of the Stokes parameters of the Lyman-α radiation on the angle of tilt after the interaction of 70-keV $H^{\pm}$ ions with a carbon foil 4 $\mu g/cm^2$ thick. The data at $\alpha \approx 88°$ are obtained by reflecting the projectiles at the foil surface [see Fig. 1(b)].

the "electron-density gradient model" by Schröder and Kupfer[6] which simply results in a $\sin(\mathbf{v}, \nabla n_e) = \sin\alpha$ dependence of S/I. In the calculations of Ref. 6 and subsequent papers[7,15,16] the absolute quantity of the polarization is generally found to be much too large. An open question up until now is whether this discrepancy between experiment and theory is caused by an incomplete description of the interaction process or by experimental problems like quality of the foil surface, etc.

In experiments where H^+ ions interact with clean monocrystalline Ni or Si targets at grazing incidence under ultrahigh-vacuum conditions, we found S/I up to 60% for Lyman-α radiation.[17] This result clearly indicates that the "quality" of the surface of the foil plays a very important role for the polarization production mechanisms. From these findings it is very likely to assume that foils with surfaces which are more well defined than carbon foils may produce larger anisotropies in the population of excited terms. The observation of larger nuclear orientations achieved by stretched thin plastic foils by Goldring *et al.*[18] may serve as an indication of the validity of that statement. In theoretical approaches Kupfer and Gabriel[16] and Schröder and Gabriel[7] take the "quality" of the foil surface into account and find a drastic reduction in anisotropy which agrees reasonably well with the data.

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