ORIENTATION AND ALIGNMENT OF ATOMS BY BEAM-FOIL EXCITATION

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We have measured the beam energy and foil tilt angle dependence of the orientation and alignment of the $3p^1P$ state of ^{4}He I after beam-foil excitation. The results for carbon and aluminum foils are compared.

We have shown earlier [1] that the polarization state of the light emitted in the ^{4}He I, 2s ^{1}S–3p ^{1}P transition after beam-foil excitation depends upon the tilt angle of the foil with respect to the beam. Specifically, we observed that tilting the foil surface direction away from the beam axis destroys the cylindrical symmetry of the source and gives a net orientation to the excited atoms which consequently emit circularly polarized light. We should note that Lombardi [2] produced orientation of a beam of aligned atoms by differential relaxation in an electric field inclined relative to the alignment axis. This may be a very similar effect to the production of orientation at the final surface of the foil.

The orientation and alignment of the excited atoms can be obtained from measurements of the fractional circular and linear polarizations observed at a fixed angle to the beam axis, as shown previously [1]. In this paper, we present investigations of the orientation and alignment as functions of the foil tilt angle, the beam energy, and the foil material.

The experimental arrangement was the same as described previously [1]. In this experiment we observed light emitted from ^{4}He I, 2s ^{1}S–3p ^{1}P at 5016 Å at 90° to the beam axis and measured its Stokes parameters to obtain the circular polarization fraction S/I and the linear polarization fraction M/I (using the notation of ref. [1]).

The foil tilt angle dependence was measured at 130 keV beam energy with carbon foils of 5 $\mu g \cdot cm^{-2}$ at 12 different tilt angles, while the energy dependence was measured with carbon and aluminum foils tilted at 30° at beam energies between 45 keV and 350 keV.

Fig. 1(a) shows that the circular polarization is satisfactorily fitted by a dependence of the tilt angle α of the form α or $\sin \alpha$ but not $\sin^2 \alpha$ and higher powers. The circular polarization is directly proportional to the atomic orientation and represents the net angular momentum of the excited atoms along the viewing direction [1, 3]. Classically, such angular momentum could be produced by a torque which arises from the electromagnetic interaction of the atom leaving the foil surface. For example, a form for the torque which will satisfy the $\sin \alpha$ dependence is the vector product of a force along the surface normal with the beam velocity. A detailed theory of the beam-foil surface interaction is necessary to determine the torque more explicitly.

This torque applied to the moving atom would naturally go to zero as the atom velocity goes to zero and such a dependence is observed in fig. 1(c). Especially for the more accurate results using the carbon foil, the orientation is monotonically increasing with the atom velocity.

The results of the energy dependence of the alignment (fig. 1(b)) and the orientation (fig. 1(c)) are quite unexpected. Thus, at 350 keV beam energy, where the alignment has reached zero, the orientation shows its maximum value. This suggests that the interaction mechanism for producing the orientation, necessarily at the foil surface, is at least partially independent of that producing the alignment. In particular, the alignment may also be dependent upon the interactions of the moving atom within the bulk of the foil material. The modulations of the fractional alignment with beam energy previously observed by

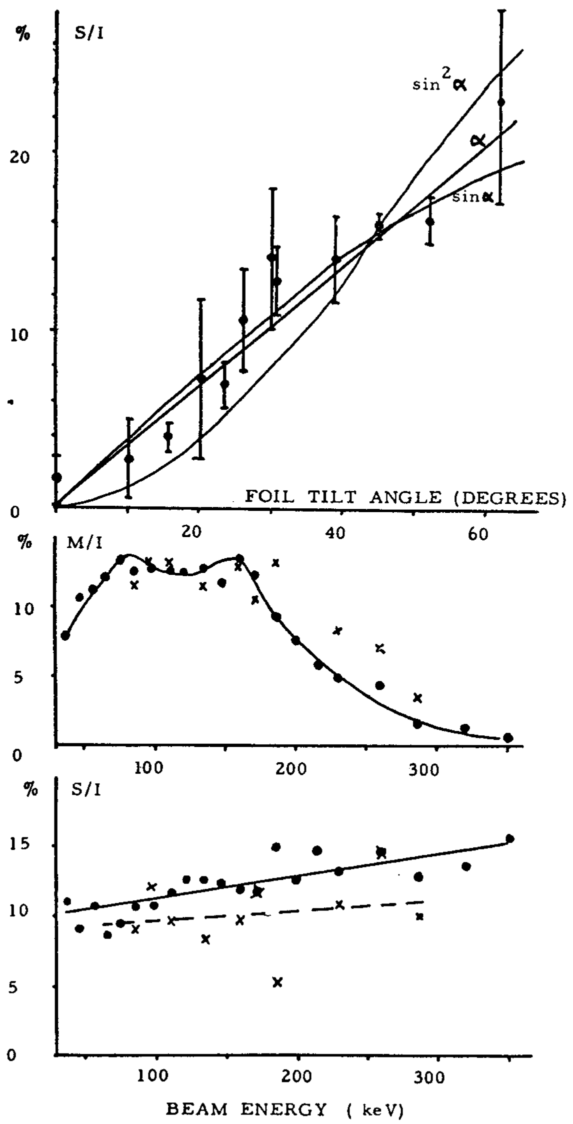

Fig. 1. Fractional polarizations of the 5016 Å, $2s\,^1S$-$3p\,^1P$, ^{4}He I transition. Part (a) shows the circular polarization as a function of foil tilt angle α. The solid lines are fits to α, $\sin\alpha$ and $\sin^2\alpha$. Parts (b) and (c) show the linear and circular polarization fractions, respectively, as a function of beam energy for a carbon foil (•) and an aluminum foil (x).

Berry et al. [4] with a perpendicular foil ($\alpha = 0$) also appear to be present with the 30° foil with smaller variations.

Our statistics for the measurements of alignment and orientation with the aluminum foils are not as good, but they tend to show similar energy dependences. The orientation is slightly reduced, while the alignment is stronger at higher energies. Further measurements are necessary to establish the variation with foil material. We might expect that the electron capture probability in different materials will affect the induced alignment and orientation.

An important corollary to our result showing orientation with little or no alignment is that observation of fine and hyperfine structure quantum beats may often become easier using the tilted foil geometry. The lack of strong alignment in the normal beam-foil source has been a principal difficulty in such measurements and the tilted foil technique may be useful for both quantum beat hyperfine structure and *g*-value measurements.

References

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