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Anisotropic Excitation by Foils and Surfaces

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Abstract. Recent theories for the production of orientation and alignment in fast ion excited levels by collision with foils or surfaces have emphasized the development of the excited state from an initial state inside the material defined by a density matrix with particular symmetry properties. Due to the path length inside the material, and to the lesser degree of deflection of the fast ions, the initial states defined by a foil collision will not necessarily have the same character as those defined by a collision with a solid. Coherence measurements of orientation and alignment of excited D levels of He, B, and N atoms and ions produced by collisions with carbon foils and carbon-coated solids are contrasted to distinguish such differences in final states which may be correlated with the initial distribution of charge and momentum.

Introduction

Fast ions excited and deflected through small angles by surface collisions exhibit a high degree of orientation of the excited levels, but relatively less alignment [1]. The momentum transfer in the collision appears consistent with binary collisions at or near the surface, with little penetration of target material [2]. These results may be contrasted with the anisotropy produced in excited levels due to the passage of ions through a thin foil with normal inclined to the beam direction, [3,4] where significant alignment is also sometimes observed [5]. Even for thin foils, the increased traversal distance due to large foil angle inclination produces considerable slowing and scattering of the incident beam. The bulk scattered ions then emerge from the surface with various directions, but little information about the momentum transfer in the final exciting collision is available. It has been shown, however, that only the direction of the ions relative to the surface material normal is the significant parameter in surface collisions [2], and similarly, the significant parameter in foil collisions is the velocity relative to the exit surface normal, independent of the inclination of the foil [6].

Theories by Herman, [7] Band, [8] and Silver [9] assume an axially-symmetric initial density matrix for foil-excited ions, which is also symmetric under reflections in any plane containing this symmetry axis. This matrix is modified by capture, excitation, or precession when the ion emerges from the foil surface, to produce the alignment and orientation. For small-angle ion-surface collisions, Schröder [10] assumes that single or multiple charge capture is the principle mechanism for orienting the excited levels, although core polarization may also play a role.

At comparable inclination angles, one may hope to distinguish differences or similarities in relation to the foil or surface excitation processes by examining the relative magnitudes of the orientation parameter [11] \( \alpha_{01} \) and of the three alignment parameters \( A_0^1, A_1^1, \) and \( A_2^1 \) produced by collisions of each type. Considered here are \( ^1D \) levels...
of three configurations in two light ions and one atom. \textsuperscript{1}D levels are the lowest L level for which higher order (unobserved) anisotropic tensor moments can be coupled into moments observable by light polarization, and also are interesting since core polarization may affect the anisotropy in multiple capture processes \cite{10}.

Experimental Method

To obtain similar data, light from a small range of scattering angles was collected in each case. In a typical beam foil coherence measurement, light emitted from ions scattered into a range of angles up to $\pm 8^\circ$ could be collected. Since the emergence angle of the fast projectiles is the critical parameter, the observation region for ion-solid scattering was positioned at the end of the target surface. This geometry was chosen to be closer to the foil scattering average, although the mean orientation measured in this configuration is approximately 10\% below the maximum obtained when light is collected from a minimal angular range well downstream \cite{2}.

The experimental configurations are shown schematically in Figure 1 (a) and (b). A coherence measurement technique was used in each case, \cite{5} with polarization analyzers fixed in angle for a given measurement. The emitted polarized light was collected from a narrow spatial region as a function of a linearly swept magnetic field strength. In the case of foil excitation, this produced a quantumbeat signal, while for a solid target a finite-time Hanle-effect signal \cite{7,13} was observed. In each case, the relative modulation of the analyzed light intensity is related to two or more of the four orientation and alignment parameters. In quantumbeat signals, these modulations often occur at different multiples of the Larmor frequency. Four separate relative polarization measurements are sufficient to obtain the magnitude of the four multipole parameters \cite{5}.

The transitions and levels investigated were the 4922\AA\ transition from the 1s4d\textsuperscript{1}D level of He I, the 3451\AA\ transition from the 2p\textsuperscript{2}1\textsuperscript{D} level of B II, and the 3996\AA\ transition from the 2p3p\textsuperscript{1}D level of N II.

![Figure 1: (a) foil excitation configuration (b) surface excitation configuration](image)

![Figure 2: (a) Anisotropy parameters for foil excitation and (b) surface excitation](image)

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>60</th>
<th>80</th>
<th>95</th>
</tr>
</thead>
<tbody>
<tr>
<td>foil angle (degree)</td>
<td>83</td>
<td>.052</td>
<td>.050</td>
</tr>
<tr>
<td>surface angle</td>
<td>85</td>
<td>.030</td>
<td>.030</td>
</tr>
</tbody>
</table>

Table 1: $\alpha_{\text{col}}^1$ vs $\beta$

Magnitude of $\alpha_{\text{col}}^1$ for the He I 4d \textsuperscript{1}D state excited by carbon.
Table II

<table>
<thead>
<tr>
<th>Ion level</th>
<th>Energy (keV)</th>
<th>$\alpha_{1}^{\text{Col}}$</th>
<th>angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>NII $^1D$</td>
<td>120</td>
<td>0.050±0.002</td>
<td>86°</td>
</tr>
<tr>
<td>BII $^1D$</td>
<td>120</td>
<td>0.050±0.002</td>
<td>86°</td>
</tr>
<tr>
<td>HeI $^1D$</td>
<td>125</td>
<td>0.032±0.004</td>
<td>86°</td>
</tr>
<tr>
<td>HeI $^1D$</td>
<td>60</td>
<td>0.030±0.006</td>
<td>85°</td>
</tr>
</tbody>
</table>

Magnitude of $\alpha_{1}^{\text{Col}}$ for several levels

Results and Discussion

The principal results for the 4d $^1D$ level of He I are shown in Table I and Fig. 2. The inclination angles for each measurement type are slightly different, but the variations of the parameters over a few degrees in this range are not discontinuous. The energy tabulated for the surface collision is the incident ion energy, while the energy tabulated for foil excitation is the exit ion energy based on tabulated energy losses. One see that in both cases non-negligible alignment larger then the orientation is present: an unusual situation for ion-solid scattering, where alignment is often neglected compared to the orientation in theoretical treatments. In particular, the ion-surface collision emphasizes the alignment parameter $A_0^{\text{Col}}$ and $A_2^{\text{Col}}$, while $A_2^{\text{Col}}$ is largest for the ion-foil collision. The foil-generated orientation is larger than that generated by the surface, but is converging toward the surface value (Table I). The largest value of $\alpha_{1}^{\text{Col}}$ is about 25% of the theoretical maximum.

In Table II is a comparison of the orientations measured for the $^1D$ levels of the ions and the He atom, all for surface scattering from a carbon target. Data are shown both for comparable energies, and for comparable velocities. The coherent alignment tensor moments for both ion levels were less than 2%.

Both ions have a nuclear spin, so the observed orientation limits: some of the electronic orientation could be coupled into the nucleus during the free precession interval. Since the external magnetic field was present the amount of this reduction is uncertain. For maximum coupling, the true electronic orientation would be increased over the observed value by a factor of 1.55 for $^{11}B$ and 1.26 for $^{14}N$. In any event, the orientation of the ions in both configurations is significantly higher than the atom orientation.

Conclusions

The anisotropy in the $^1D$ levels of ions produced by carbon surface collisions is primarily orientation, while the 4d$^1D$ level of neutral helium similarly excited shows a considerably smaller orientation, and correspondingly larger alignment. Foil excitation of the same He level at comparable emergence angles also favors alignment. The results indicate that the two types of collision are certainly related for the formation of this level, but they are not completely equivalent. This favoring of certain alignment components may be related to different momentum transfer in the final collision, or to differences in capture probability in the formation of the final state.

Acknowledgment

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BIBLIOGRAPHY

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