Summary

We have measured the intensity and polarizations of light emitted from atomic excited states of dissociated molecular ions. The dissociations are induced when fast molecular ions (50-500 keV/amu) are transmitted through thin carbon foils. A calculation of multiple scattering and the Coulomb explosion gives the average internuclear separation of the projectile at the foil surface. Experimentally, we vary the foil thickness to give varying internuclear separations at the foil surface and observe the consequent variation in light yield and optical polarization. Using HeH+ projectiles, we have observed factors of 1-5 enhancements of the light yields from n=3, 4, 5, 6 states of He I and some He II and H I emissions. The results can be explained in terms of molecular level crossings which provide mixings of the various final states during dissociation of the molecular ions at the exit surface. They suggest a short range surface interaction of the electron pick-up followed by a slow molecular dissociation. Alignment measurements confirm the essential features of the model. Observations of Lyman-α emission after dissociation of H2+ and H3+ show rapid variations in light yield for small internuclear separations at the foil surface.

Introduction

In recent investigations of the beam-foil interaction, we have shown that the excited state distributions produced after the foil are sensitive to the foil temperature. Observations of light yields from excited helium transitions show similar increases in optical polarization when the foil is heated either by the beam itself in energy loss collisions, or by external heating. We believe the principal change in the interaction which occurs at increased temperature is the change in flux of secondary electrons. Figure 1 shows schematically the secondary electron production by a fast moving helium ion passing through a thin carbon foil. 5 to 15 secondary electrons are emitted from the foil at the exit surface. Several experiments show that the outgoing ion undergoes charge exchange and excitation to its final state very close to this final surface (at velocities of 0.5v₀ to 5.0v₀, where v₀ is the Bohr velocity, 2.2 × 10⁸ cm. s⁻¹). These processes are expected to be sensitive to the secondary electron distributions, in energy, angle and number. Very little is known about such distributions. However, Sterneheimer has predicted a reduction in secondary electron emission at increased temperatures, due to increased phonon interactions. These interactions reduce the secondary escape depth, and hence the total number of secondary electrons emitted. As the first order, the angle and energy distributions remain unchanged. We have measured the rate of change of secondary electron production as a function of He⁺ ion beam energy. This is shown in Fig.2, and compares well with the stopping power curve for He⁺ ions in thin carbon foils.

We have measured the atomic alignment of

Figure 1. The fast-ion foil interaction.

Figure 2. The rate of change of electron flux per unit temperature change versus beam energy. The total stopping power curve for He⁺ is normalized at 117 keV.
the \( n = 3 \) states of helium excited by perpendicular thin carbon foils over a large range of beam energy, as shown in Fig. 3. These observed alignments are similar to single collision electron-atom excitation results, and suggest that excitation rather than electron pick up constitutes the final interaction at the surface.

It is difficult to decouple effects due uniquely to temperature from those caused by electrons. However, we can introduce positive charged particles in the interaction region by using molecular ions instead of the usual atomic ions. As the molecule enters the foil, its electrons are stripped away and it dissociates, broken apart by the combined effects of internuclear Coulomb repulsion and multiple scattering from the electrons and nuclei of the foil. The average distance between each constituent increases monotonically with foil thickness. Thus, we may vary the charge distribution about each emerging ion without changing the foil temperature. More generally, by altering the basic surface-ion excitation in a relatively well-defined manner, we may gain new specific information about such processes.

**Alignment Results**

We have measured\(^4\) the polarization production of the 4 transitions \( 2p \rightarrow 3p, 3d \rightarrow 3p \) and \( 2s \rightarrow 3s \rightarrow 3p \) for carbon foil excited He I using HeH\(^+\) and He\(^+\) incident projectiles at energies between 125 and 650 keV exit He energy. In general, the magnitude of the alignment is reduced for very thin foils and HeH\(^+\) projectiles over that for He\(^+\) projectiles or thick foils. In Figs. 4-7, we show the results for the alignment, \( A_{\text{coll}} \), for the upper terms of the four transitions. These alignments were obtained by suitably averaging over the zero field fine structure quantum beats of the triplet transitions. Note that increased foil thicknesses correspond to increased internuclear separation of the He\(^0\) and the proton (or H\(^0\)) at the final surface where the production of the excited state takes place.

We infer from the data that the foil thickness at which the alignments using HeH\(^+\) projectiles equal those using He\(^+\) projectiles corresponds to the internuclear separation at which molecular influence on the alignment becomes negligible. We expect this internuclear separation is also close to the distance from the foil surface at which the
Figure 6. He I 3d 3D alignment versus foil thickness for HeH+ and He+ beams.

Figure 7. He I 3p 3P alignment versus foil thickness for HeH+ and He+ beams.

Figure 8. Relative intensity of several transitions in He I, He II, and H I, data being smoothed by eye. All intensities are normalized to the equilibrium value. HeH+ incident; 650 keV He exit energy.
We have measured the intensity of Ly as a function of carbon foil thickness with $H_2^+$ and $H_3^+$ projectiles and we present some preliminary results in Figure 9. The measurements were made at energies of 0.2-0.5 MeV/amu.

The dwell time $t$ of the projectiles within the carbon foil determines the internuclear separation $R$ at the foil exit surface. In terms of both these parameters, $t$ and $R$, the intensity results at each beam velocity fit well to a sum of two exponentials, and all points fall on single curves, one each for $H_2^+$ and $H_3^+$ projectiles.

The light yields are strongly enhanced for both $H_2^+$ and $H_3^+$ projectiles with very thin foils. However, the decay rate is close to twice as fast for the $H_3^+$ projectiles as for the $H_2^+$ projectiles. These results are in quite sharp contrast to the molecular enhancement of hydrogen neutrals measured by Gaillard et al. After accounting for non-equilibrium effects near the front surface of the foil, they find only a small molecular dependence of the neutral production. The two sets of results can be consistent if the $n=2$ production is only a small fraction of the total neutral hydrogen production. We are also investigating the molecular dependence of neutral populations in more highly excited hydrogen through Balmer series emission to explain these differences.

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References