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Wigner spin rule in N^+-Kr and N^+-Xe collisions*

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The $^1D \leftrightarrow {}^3P$ and $^1S \leftrightarrow {}^1D$ transitions in N^+ have been observed in the energy-change spectra of 1–4-keV N^+ scattered from Kr and Xe. In contrast to the case for scattering from the lighter rare gases, the spin-nonconservative $^1D \leftrightarrow {}^3P$ transitions occur with high probability in the N^+-Kr and N^+-Xe collision systems.

In a previous investigation of electronic transitions which occur in non-charge-changing collisions between N^+ and He, Ne, Ar, N_2, and O_2, the only observed transitions which occurred with high probability were those for which the Wigner electron-spin conservation rule was obeyed.[1] According to the Wigner rule, the total electron-spin angular momentum of a collision system is conserved when there is weak coupling between electron-spin and orbital angular momentum. This paper reports an extension of the previous N^+ experiments to include collisions with Kr and Xe. In contrast to the earlier work, the N^+-Kr and N^+-Xe systems exhibit strong spin-orbit coupling.

In these experiments the energy change of 1–4-keV N^+ inelastically scattered from static gas atoms is measured with a resolution of about 170 meV. The ion beam contains a mixture of ground state and metastable N^+. The state population in the beam corresponds approximately to a 16 000 °K Boltzmann distribution.[1]

The processes of interest in the interaction of the mixed N^+ beam with rare-gas targets are transitions involving the low-lying states of the projectile ions. Inelastic processes result in peaks at 1.90 and 2.15 eV in the N^+ energy-loss spectrum. These peaks correspond to the $^1D \leftarrow {}^3P$ and $^1S \leftarrow {}^1D$ transitions, respectively. Superelastic peaks at −1.90 and −2.15 eV are the result of the $^1D \rightarrow {}^3P$ and $^1S \rightarrow {}^1D$ transitions.

In collisions with singlet-state targets the $^1S \leftrightarrow {}^1D$ transitions are spin-conservative since the total spin angular momentum of the collision system is zero before and after the collision. The $^1D \leftrightarrow {}^3P$ transitions are spin-nonconservative since the resultant spin quantum number of the two species which make up the collision system is 0 before the collision and 1 after.

In the energy-loss spectrum of N^+ scattered from Ar in Fig. 1 (a), the only prominent features are the spin-conservative transitions, $^1S \leftrightarrow {}^1D$, at ±2.15 eV. In the spectra of N^+ scattered from Kr and Xe illustrated in Figs. 1 (b) and 1 (c), the spin-nonconservative transitions at ±1.90 eV are the most intense peaks. The $^1S \leftarrow {}^1D$ transition produces the shoulder at 2.15 eV in these spectra. In the Kr and Xe spectra it is of interest to compare the intensities of the −1.90- and +2.15-eV peaks since these are both the result of transitions involving the ^1D component of the N^+ beam. Because the energy defect for these two processes—$^1S \leftarrow {}^1D$ and $^1D \rightarrow {}^3P$—are similar, it is not unreasonable to assume that the cross sections for these processes would be about equal were not one of the processes spin-conservative and the other spin-nonconservative. If the spin conserva-

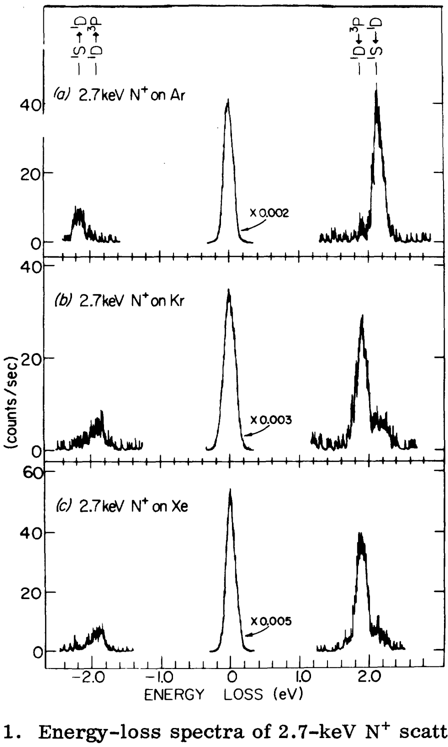

FIG. 1. Energy-loss spectra of 2.7-keV N^+ scattered about 0° from (a) Ar, (b) Kr, and (c) Xe. The target-gas pressure in each case was between 5 and 10 mtorr. All spectra were taken with a scan speed of 1.0 eV/min. The expected positions of several N^+ transitions are indicated.

tion rule did not apply, the relative intensity of the two peaks would be a function only of the statistical weights of the final states of the transitions since the initial states are identical:

$$\frac{I({}^1S \leftarrow {}^1D)}{I({}^1D \rightarrow {}^3P)} = \frac{g({}^1S)}{g({}^3P)} = \frac{1}{9}\,.$$

As can be seen in Figs. 1 (b) and 1 (c) this intensity ratio is more nearly unity than $\frac{1}{9}$. This implies that the Wigner rule holds weakly for the N^+-Kr and N^+-Xe collision systems.

The intensity of the ${}^1D \rightarrow {}^3P$ peak relative to that of the ${}^1D \leftarrow {}^3P$ peak is a function of the relative population of the ${}^1D$ and ${}^3P$ states in the beam. The intensity ratio $I({}^1D \rightarrow {}^3P)/I({}^1D \leftarrow {}^3P)$ was measured to be 0.22 ± 0.04 for the Kr and Xe spectra. This ratio corresponds to a Boltzmann temperature of $14\,500 \pm 2000$ °K which agrees with the temperature determined previously from He, Ne, Ar, and N_2 spectra.

The present experiments indicate that there is strong spin-orbit coupling in collisions with the heavy rare gases. This result is in agreement with the work of Fournier *et al.*, who observed that the Wigner rule applies for double-charge-exchange collisions of H^+ with the lighter rare gases but the rule fails in collisions with Xe.[2] The present result is analogous to the observation from optical spectroscopy that (L, S) coupling predominates in light atoms while (j, j) coupling is more important in the excited states of heavy atoms.

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[1] J. H. Moore, Jr., Phys. Rev. A 8, 2359 (1973).

[2] P. Fournier, R. E. March, C. Benoit, T. R. Govers, J. Appell, F. C. Fehsenfeld, and J. Durup, in *Electronic and Atomic Collisions, Abstracts of Papers on the Eighth International Conference on the Physics of Electronic and Atomic Collisions, Belgrade* (Institute of Physics, Belgrade, 1973), p. 753.