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Inelastic Scattering of N_2^+ by Helium

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While studying the reactive scattering of 25-125 eV N_2^+ ions with H_2, D_2, and HD, we investigated the scattering of 90 eV N_2^+ by helium. The anticipated elastic scattering was found at small angles (<30°) in the center of mass system, but the N_2^+ detected at angles between 50° and 180° had clearly undergone inelastic scattering with a relative kinetic energy loss of up to 3.4 eV. The magnitude and continuous variation of this energy loss suggests that the projectile N_2^+ acquires substantial rotational and vibrational energy as a result of the collision with helium. This appears to be the first such inelastic scattering of a molecular ion reported, and the first study of relative kinetic energy loss as a function of scattering angle.

Experiments were performed by allowing a well-collimated, momentum analysed beam of 89.86 eV N_2^+ to impinge on He gas at 4×10^{-4} Torr in a scattering cell. The energy spread of the beam was 0.8 eV (full width at half maximum). Ions leaving

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the scattering cell entered a 90° spherical electrostatic energy analyser having a transmission band of 3% E (FWHM) were then focused into a quadrupole mass spectrometer and detected by an ion counter. The complete detection system and the exit aperture of the scattering cell were mounted on a rotatable lid. The detector could be positioned in a range of ±55° from the primary beam, sufficient to explore the complete angular distribution of scattered N_2^+, which was confined to ±10° in the laboratory system.

The N_2^+ intensity distribution was determined by scanning the detector angle at a fixed analyser energy, or by scanning the energy at fixed angle, and recording the counting rate at closely spaced points. Each intensity was reduced by the corresponding background count (negligible outside the unscattered beam profile) and then was normalized to the ion beam intensity, the scattering cell pressure, the transmission band of the energy analyser, and the scattering volume subtended by the detector at the different scattering angles.

Seven profiles of the complete N_2^+ intensity distribution were obtained. In Fig. 1a, the points of maximum intensity are plotted on a polar graph as a function of the velocity relative to the center of mass. For elastic scattering the maxima should lie on the inscribed circle of radius (4/32) g, where g is the initial relative speed. It is clear that as the scattering angle increases, the final relative speed decreases below that expected for elastic scattering.

The accuracy of the ion energy determinations are supported by the agreement of our unpublished measurements of the velocity spectra of the products of the N_2^+-H_2-D_2 reaction with the results of others, but more significantly by the agreement between the experimental and calculated energies of the ions elastically scattered through 180° from Ar^+-He collisions. In Fig. 1b we show the profiles of the Ar^+ and N_2^+ peaks at 180° plotted relative to the calculated velocity for elastic scattering. The deviation of the N_2^+ peak from the velocity expected for elastic scattering is unmistakable. The N_2^+ profile is also significantly broadened compared to the Ar^+ peak.

The exothermicity Q of the collision is defined as the final minus the initial relative kinetic energy. Figure 1c shows Q plotted as a function of the center of mass scattering angle. Also shown are the results of an experiment with an ion energy of 59.95 eV. Because of the great sensitivity of Q to small errors in measurement of the laboratory angles and kinetic energies, no significance is attributed to the detailed shape of the Q-χ curves. However, the clear trend of increasing endothermicity with increasing scattering angle confirms the intuitive expectation that small impact parameter collisions are more likely to produce inelastic scattering than are the grazing collisions responsible for small angle scattering.

The nature of the inelastic process which occurs cannot be deduced directly from our experiments. However, only N_2^+ has internal energy levels less than 3.5 eV above the ground state. The apparent onset of inelastic scattering at relatively small angles suggests rotational excitation of N_2^+. The magnitude of the energy loss at 180° makes vibrational excitation seem very likely. Because the A $^2\Pi_\mu$ state of N_2^+ lies only 1.12 eV above the ground state, electronic excitation is possible. If an electronic transition occurs at all, it must be accompanied by vibrational and rotational excitation. We expect that continuing studies of the scattering over a range of primary beam energies and with other targets will clarify the nature of the excitation.

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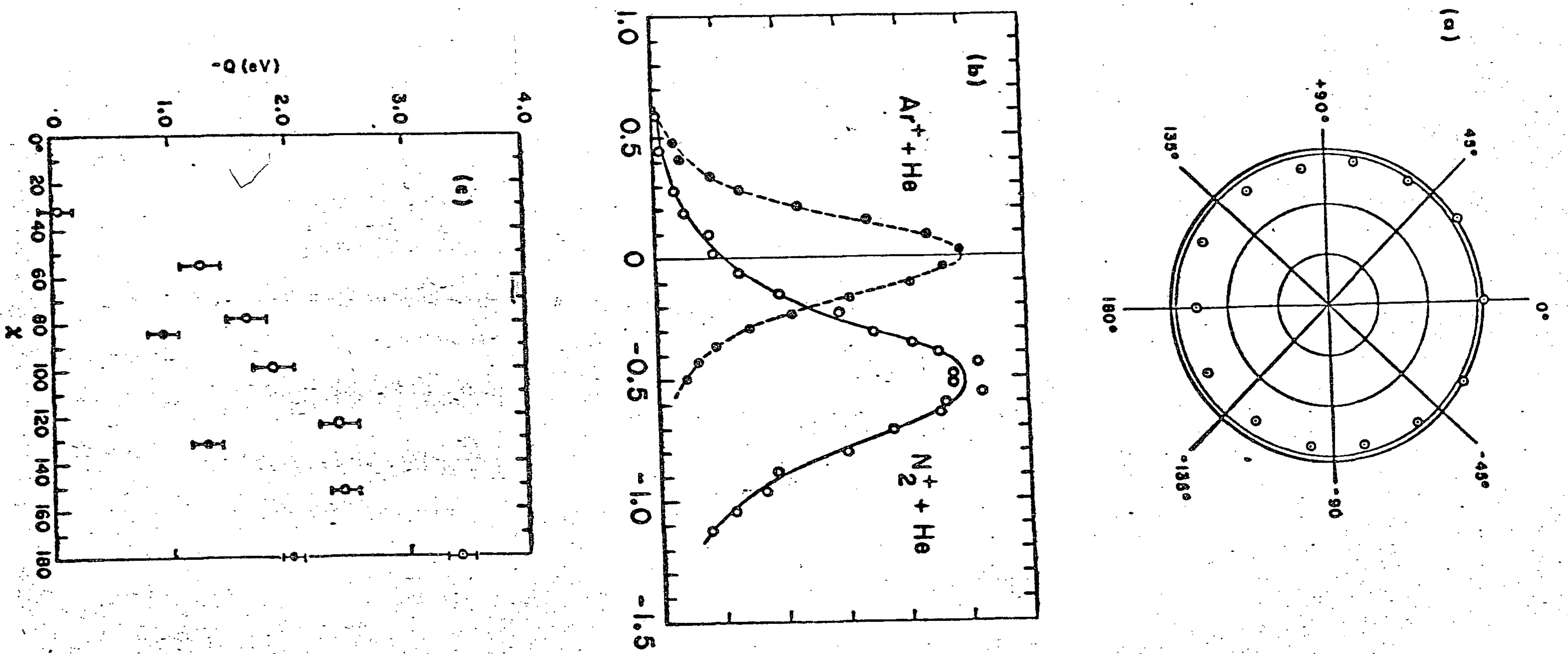

Figure 1. Scattering of N_2^+ and Ar^+ by He.

a. Location of intensity maxima for 90 eV (lab) N_2^+ plotted in the center of mass coordinate system. The radial scale is 10^5 cm/sec.

b. Velocity profiles of Ar^+ and N_2^+ scattered by He through 180° in the center of mass system. Velocities relative to the center of mass are plotted as deviations from the calculated velocity for elastic scattering in units of 10^5 cm/sec.

c. The endothermicity of the intensity maxima plotted as a function of center of mass scattering angle. Open circles, 90 eV N_2^+; closed, 60 eV N_2^+. Error bars are our estimate of the uncertainty of the location of intensity maxima.

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