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INELASTIC SCATTERING OF $N_2^+$ BY HELIUM

W. R. Gentry, E. A. Gislason, B. H. Mahan, and Chi-wing Tsao

June, 1967
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 N₂⁺, which was confined to ±10° in
the laboratory system.

The N₂⁺ 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 sub-
tended by the detector at the different scattering angles.

Seven profiles of the complete N₂⁺ 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 \( \text{N}_2^+ - \text{H}_2 - \text{D}_2 \) 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 \( \text{Ar}^+ - \text{He} \) collisions. In Fig. 1b we show the profiles of the \( \text{Ar}^+ \) and \( \text{N}_2^+ \) peaks at 180° plotted relative to the calculated velocity for elastic scattering. The deviation of the \( \text{N}_2^+ \) peak from the velocity expected for elastic scattering is unmistakable. The \( \text{N}_2^+ \) profile is also significantly broadened compared to the \( \text{Ar}^+ \) 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 \( Q-\chi \) 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 \( \text{N}_2^+ \) 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 $180^\circ$ makes vibrational excitation seem very likely. Because the $A^2\Pi_u$ 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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