N^{2+} formation in collisions between N^+ ions and rare gases

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Total cross sections for single-electron loss of N^+ ions impinging on Ne, Kr, and Xe were measured in the energy range from 1.5 to 5.0 keV. The measured electron-loss cross sections show a monotonically increasing behavior as a function of energy of the incident beam for all the targets studied. Our results are compared with previous experimental data and are found to be in excellent agreement.

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I. INTRODUCTION

Since N^{2+} is only 44 eV above its neutral ground state, it can easily be produced by a variety of mechanisms, such as electron-impact ionization, dielectronic recombination, photoionization, and charge transfer. Electron-transfer collisions with helium, atomic and molecular hydrogen, nitrogen, carbon monoxide, and other molecules at mean collision energies of a few eV can play an interesting role in regulating the energy, and therefore the characteristics of the plasma in these regions of energy.

There are a few experiments [1–4] where the single-electron-loss (SEL) cross sections of N^+ ions in collision with targets of rare-gas atoms have been measured. Lo and Fite [1] reviewed SEL cross sections of N^+ ions passing through gases. Vujovic *et al.* [3] measured the SEL cross section in the energy range 2–30 keV for the ground state of N^+ ions, and in the range 5–20 keV for metastable-state N^+ ions in collision with inert gases. Hird and Suk [2] measured the SEL of N^+ in Ne, Ar, and Kr between 35 and 140 keV. Pivovar, Novikov, and Dolgov [4] carried out measurements of the SEL of N^+ ions on Ne, Ar, and Kr atoms in the energy range 250–1400 keV and Dmitriev *et al.* [5] reported measurements of SEL cross sections of N^+ ions on He, Ne, and Kr for energies between 500 and 2400 keV. However, for Ne as a target, there is a systematic disagreement by about 50% between the results of Lo and Fite [1] and Pivovar *et al.* [4] above 300 keV, where the two sets of data overlap; and the results of Vujovic *et al.* [3] are in good agreement with the results of Hird and Suk [2], while those of Lo and Fite [1] are 30% lower. In addition, there is no measurement of SEL cross sections in the low-keV energy range. Therefore it is important to carry out additional measurements for the N^+–rare-gas-atom collisions at lower energies using a different experimental technique.

The present work is intended to investigate the dependence of the single-electron-loss cross sections of N^+ on the physical parameter E (incident energy). Data were measured for 1.5–5.0 keV.

II. EXPERIMENT

The experimental apparatus and technique needed to generate the fast-ion beam were recently reported [6]. Briefly, the N^+ ions formed in an arc-discharge source containing N_2 gas (99.99% purity) at ion-source pressures of 0.04–0.07 mTorr were accelerated to 1.5–5.0 keV and selected by a Wien velocity filter. The N^+ ions were then allowed to pass through a series of collimators before entering the gas target cell, which was a cylinder of 2.5 cm in length and diameter, with a 1-mm entrance aperture, and a 2-mm-wide, 6-mm-long exit aperture. The target cell was located at the center of a rotatable, computer-controlled vacuum chamber that moved the whole detector assembly, which was located 47 cm away from the target cell. A precision stepping motor ensured a high repeatability in the positioning of the chamber over a large series of measurements. The detector assembly consisted of a Harrower-type parallel-plate analyzer and two channel-electron multipliers (CEMs) attached to its exit ends. The N^0 atoms passed straight through the analyzer. Separation of charged particles occurred inside the analyzer, which was set to detect the N^{2+} ions. $I_f(\theta)$ represents the particles per unit solid angle per second detected at a laboratory angle θ with respect to the incident beam direction with the lateral CEM. A retractable Faraday cup was located 33 cm away from the target cell, allowing the measurement of the incoming N^+ ion-beam current (I_0 is the number of N^+ ions incident per second on the target).

Under the thin-target conditions used in this experiment, the differential cross sections for N^{2+} formation were evaluated from the measured quantities by the expression

$$\frac{d\sigma(\theta)}{d\Omega}=\frac{I_f(\theta)}{I_0 n l}$$

where n is the number of target atoms per unit volume (typically 1.2×10^{13} atoms/cm^3) and l is the length of the scattering chamber ($l=2.5$ cm). The total cross section σ_{12} for the production of N^{2+} particles was obtained by the numerical integration of $d\sigma/d\Omega$ over all angles measured; this is

$$\sigma=2\pi\int_0^{\theta_m}\frac{d\sigma}{d\Omega}\sin(\theta)d\theta.$$

For $\theta>\theta_m$ the differential cross sections vanish.

Extreme care was taken when the absolute differential cross section was measured. The reported value of the angular distribution was obtained by measuring it with and without gas in the target cell with the same steady beam in order to eliminate the counts due to ionization of the N^+ beam on the slits and those arising from background distributions.

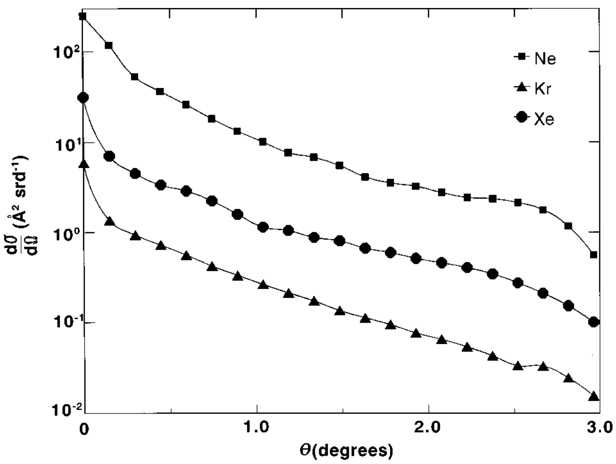

FIG. 1. Differential cross sections for single-electron loss of N^+ ions in Ne, Kr, and Xe at 3.0 keV.

The estimated rms error is 15%, while the total cross sections were reproducible to within 10% from day to day.

Changes were not observed in the values of the absolute differential and total cross sections with respect to the ion-source conditions. Also, no variation in the distributions was detected over a target-pressure range of 0.2–0.6 mTorr.

Several sources of systematic error are present and have been discussed in a previous paper [7]. The absolute error of the reported cross sections is believed to be less than ±15%. This estimate accounts for both random and systematic errors.

III. RESULTS AND DISCUSSION

Data for absolute differential cross sections (DCS's) for SEL of N^+ ions impinging on Ne, Kr, and Xe were obtained at laboratory angles $-3° \leqslant \theta \leqslant 3°$ and collision energies $1.5 \leqslant E \leqslant 5.0$ keV. We show in Fig. 1 our DCS's for SEL of N^+ in Ne, Kr, and Xe at the collision energy of 3.0 keV. The behavior of the DCS's is qualitatively identical for all the energies for each of the targets studied. All curves plotted in Fig. 1 show a monotonic decrease in the DCS with increasing angle. The differential cross sections were integrated to yield total cross sections. Figures 2(a)–2(c) show a comparison of our values for the total cross sections for the three collision systems with the data of various other groups. The error bars are given to indicate the maximum reproducibility of the data in the present energy range (15%).

The total cross sections obtained for SEL of N^+ ions colliding with Ne are compared to experimental data in Fig. 2(a). We have included data over a wide range of energies to show the overall shape of the curve. Our results agree well with the measurement of Vujovic *et al.* [3] at 5 keV and merge smoothly into their cross sections at energies greater than 5 keV. These results give the general shape of the whole curve of single-electron-loss cross sections for the N^+-Ne system over a wide range of energies (1.5–1400 keV).

In Fig. 2(b) the total cross section obtained for SEL of N^+ ions colliding with Kr is shown as a function of collision energy. Also shown in Fig. 2(b) are other experimental results. These include measurements of Hird and Suk [2], Pivovar *et al.* [4], and Dmitriev *et al.* [5]. Although there is overlap of two sets of data at high energies (Pivovar *et al.* [4] and Dmitriev *et al.* [5]), the shapes of the cross-section data of Refs. [2], [4], and [5] and the present measurements indicate that the data from all four measurements are mutually consistent.

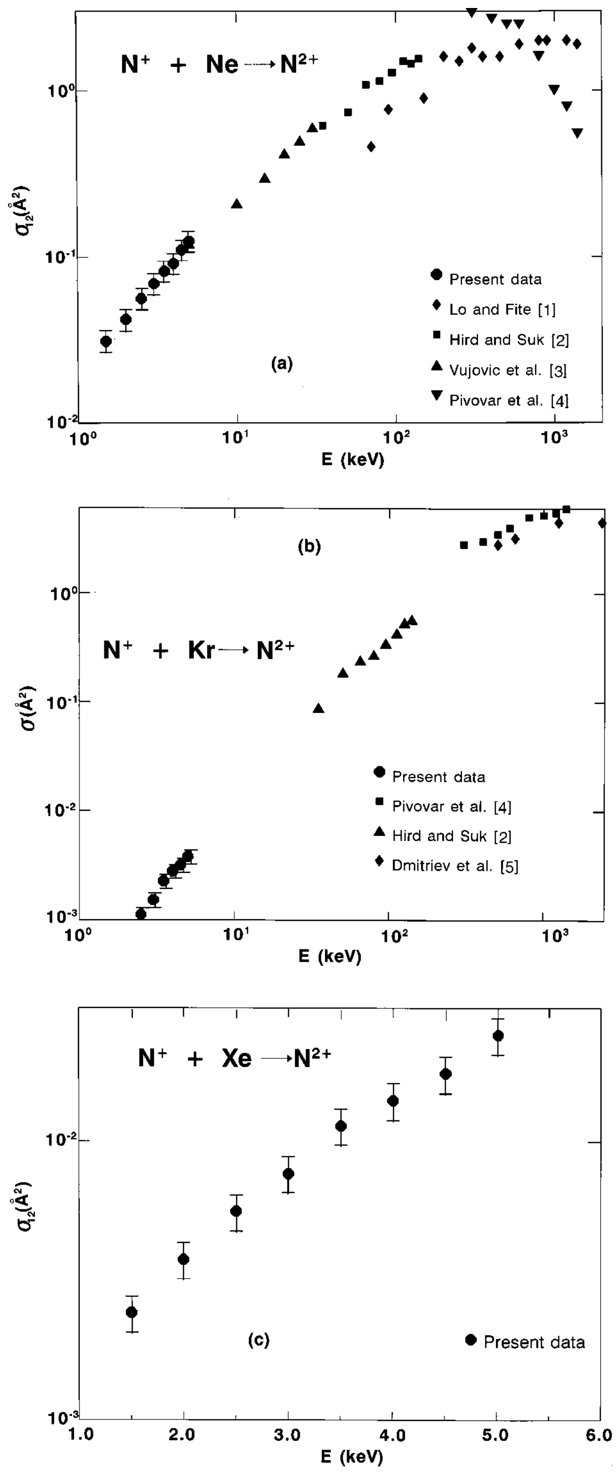

FIG. 2. Total cross sections for single-electron loss of N^+ ions in atoms: (a) Ne; (b) Kr; (c) Xe.

For N^+-Xe systems, our total cross sections for SEL of

N^+ ions colliding with Xe are found to be of order of magnitude between 10^{-3} and 10^{-2} Å^2 and show a monotonically increasing behavior as a function of the incident energy [see Fig. 2(c)]. We are aware of no previous experimental or theoretical data with which to compare the present results.

The shape of the cross section for all three reactions shows a monotonically increasing behavior as a function of the incident energy. This behavior can be explained qualitatively in terms of momentum transfer and projectile-target interaction time. For energies smaller than E_{max} (the energy at which the cross section is maximum) a smaller momentum can be transferred to the projectile electrons as the energy of the projectile decreases [8].

IV. SUMMARY

The results of the present work can be summarized as follows.

(a) Absolute differential and total cross sections for SEL in N^+-atom collisions were obtained at laboratory energies between 1.5 and 5.0 keV.

(b) The SEL cross sections for all the targets studied are found to be of order of magnitude between 10^{-3} and 10^{-2} Å^2, and show a monotonically increasing behavior as a function of the incident energy.

(c) Our present total cross sections are in good agreement with an extrapolation to higher-energy data of previous experiments.

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[1] H. H. Lo and W. L. Fite, At. Data **1**, 305 (1970).
[2] B. Hird and H. C. Suk, Phys. Rev. A **14**, 928 (1976).
[3] M. Vujovic, M. Matic, B. Cobic, and P. Hvelplund, J. Phys. B **10**, 3699 (1977).
[4] L. I. Pivovar, M. T. Novikov, and A. S. Dolgov, Zh. Eksp. Teor. Fiz. **50**, 573 (1966) [Sov. Phys. JETP **23**, 357 (1966)].
[5] I. S. Dmitriev, V. S. Nikolaev, L. N. Fateeva, and Ya. A. Teplova, Zh. Eksp. Teor. Fiz. **42**, 358 (1962) [Sov. Phys. JETP **15**, 11 (1962)].
[6] H. Martínez, A. Amaya-Tapia, and J. M. Hernández, J. Phys. B **33**, 1935 (2000).
[7] H. Martínez, J. Phys. B **31**, 1553 (1998).
[8] H. Atan, W. Steckelmacher, and M. W. Lucas, J. Phys. B **24**, 2559 (1991).