He^{2+} formation in collisions between He^{+} ions and Ne atoms

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Absolute differential and total cross sections for single electron loss of He^{+} ions impinging on Ne were measured in the energy range from 2.0 to 5.0 keV. The absolute differential cross sections display a decreasing behavior with increasing angle. The measured electron-loss cross sections show a monotonically increasing behavior as a function of the incident energy and are found to be of the order of magnitude between 10^{-5} and 10^{-4} Å^{2}. The total cross section is compared with other available measurements and theoretical models at high energy. An extrapolation of the high-energy data to low energies shows good agreement with the present data.

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I. INTRODUCTION

In ion-atom collisions, one of the most important and extensively studied subjects is the processes leading to charge exchange of the collision partners. One- and two-electron atoms are the fundamental systems used in experiments and theory to test atomic processes. Conceptually, the helium ion is one of the simplest. This paper concentrates on single electron loss of He^{+} on Ne atoms. There are a few theoretical results [1–6] and several experiments [6–14] where the single-electron-loss (SEL) cross sections of He^{+} ions in collision with a target of Ne atoms were studied. Experimental studies of SEL were initiated by Jones *et al.* [7], who measured the SEL cross sections at collision energies of 25, 50, and 100 keV. Dmitriev *et al.* [8] measured the SEL cross section at 1.3, 2.4, and 8.0 MeV. Rudd *et al.* [9] measured the SEL cross sections between 10 and 2000 keV. De Castro Faria, Freire, and Pinho [10] carried out the measurement of SEL cross sections in the energy range 0.75–4.0 MeV. DuBois [11] reported measurements of SEL cross sections for energies between 15 and 2000 keV. Atan, Steckelmacher, and Lucas [12] measured the cross sections for SEL and capture of He^{+} colliding with He, Ne, and Ar, in the energy range of 0.6–2.2 MeV; and Sant'Anna *et al.* [13] measured the SEL cross section of He^{+} with various targets between 1.0 and 4.0 MeV. Finally, Fiol *et al.* [6] have measured, for 1–4 MeV collisions of He^{+} with Ne, the cross section for single and multiple ionization of the target atom with simultaneous ionization of the projectile. On the contrary, in the low keV energy range, no SEL cross sections have been measured. Therefore, it was important to conduct measurements for the He^{+}-Ne system at lower energies using a different experimental technique.

In the present work we investigated the SEL cross section dependence on the incident energy for the He^{+}-Ne collisions within the energy range of 2.0–5.0 keV.

The experimental apparatus and technique were the same as those described in Ref. [14]. He^{+} ions were formed in an arc discharge source. The ions were extracted and accelerated from 2.0 and 5.0 keV, velocity selected by a Wien filter, and deflected 10° by a cylindrical electrostatic deflection plate. The ions were allowed to pass through a Ne gas target with a thickness of 3×10^{13} atoms/cm^{2}. Laboratory angular distribution of He^{0} was measured and the absolute differential cross section was evaluated from the relation [14,15]

$$\frac{d\sigma}{d\Omega}=\frac{I(\theta)}{nLI_0}, \tag{1}$$

where I_0 is the number of He^{+} ions incident per second on the target; n is the number of target atoms per unit volume; L is the length of the scattering chamber, and $I(\theta)$ is the number of He^{0} particles per unit solid angle per second detected at a laboratory angle θ with respect to the incident beam direction. Absolute total cross sections were calculated by numerical integration. Overall uncertainties were 15%, which arise from the effective length of the target cell (3%); density determination (7%); the measurement of the incident ion current (2%); and the detector calibration (3%).

Data of absolute differential cross sections (DCS's) for SEL of He^{+} ions impinging on Ne have been obtained at laboratory angles $-2.6°\leq\theta\leq2.6°$ and collision energies $2.0\leq E\leq5.0$ keV. We show in Fig. 1, our DCS's for SEL of He^{+} in Ne at laboratory energies of 2.0, 3.0, 4.0, and 5.0 keV. All curves plotted in Fig. 1 show a monotonic decrease in the DCS's with increasing angle. The SEL data show slight structures in the DCS's, which tend to disappear as the incident energy decreases. The differential cross sections have been integrated to yield total cross sections. Figure 2 shows a comparison of our values of the total cross sections with other available measurements and theoretical models at high energies. The error bars are given to indicate the maximum reproducibility of the data in the present energy range (15%). These results give a general shape of the whole curve of SEL cross sections for the He^{+}-Ne system over a wide range of energies (2.0–8000 keV). Our total cross sections for the SEL of He^{+} ions colliding with Ne are found to be of the order of magnitude between 10^{-5} and 10^{-4} Å^{2} and show a monotonic increasing behavior as a function of the incident energy (see Fig. 2). From Fig. 2, we can see that an extrapolation of the high-energy experimental data of Jones *et al.* [7], Rudd *et al.* [9] and DuBois [9] to low energies seems to be in good agreement with the present data. Also, the present

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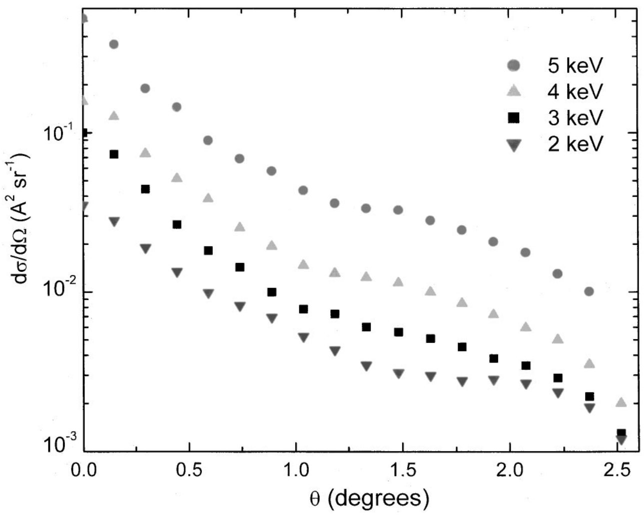

FIG. 1. Differential cross sections for single electron loss of He^+ ions in Ne atoms.

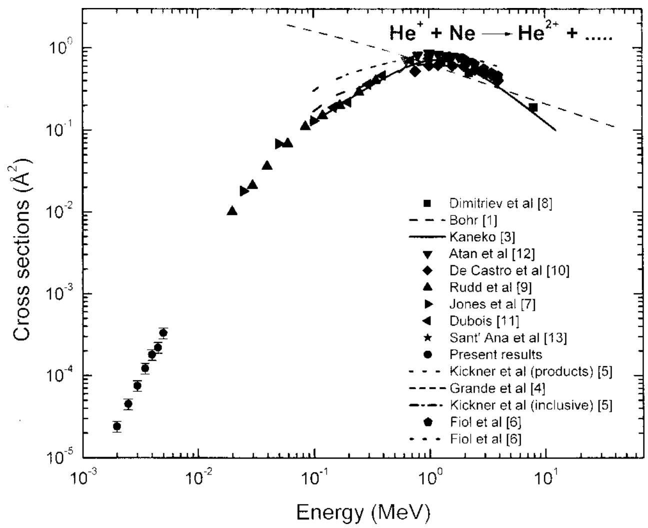

FIG. 2. Total cross sections for single electron loss of He^+ ions in Ne atoms.

data aid in an extrapolation of high-energy theories to lower energies.

The general shape of the cross section for the He^+-Ne system shows a monotonically increasing behavior as a function of the incident energy. A maximum is reached at approximately 1.2 MeV and then it decreases. This behavior can be explained qualitatively in terms of the 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 [12].

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

(a) Absolute differential and total cross sections for SEL in He^+-Ne collisions were obtained at laboratory energies between 2.0 and 5.0 keV.

(b) The SEL cross sections are found to be of the order of magnitude between 10^{-5} and 10^{-4} 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 of the higher-energy data of previous experimental data and theoretical models to low energies.

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