Ionization, Charge Transfer, and Stripping Cross Sections for Alkali Metal Ion Collisions with Inert Gas Atoms and H_2 and N_2 Molecules in the 0.5-7.0 keV Energy Range

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The absolute values of the total and differential cross sections for various inelastic processes in slow collisions of species with closed electron shells are measured. Ionization and charge transfer cross sections, σ_I and σ_C, are obtained by an improved transfer electric field (condenser) method; stripping (primary ion electron loss) cross sections σ_S by recording doubly charged primary ions, produced as a result of collisions; and differential cross sections $d\sigma/d\Omega$ by a "BOX" type electrostatic analyzer [1]. Because of the realization of these processes at small internuclear distances of colliding particles R, primary ions are scattered through relatively large angles and this is accompanied by the formation of much more energetic secondary particles (target gas ions and free electrons) than is usual. This circumstance has not been considered in earlier papers, which must raise doubts about the reliability of the measurements themselves and of the conclusions drawn from them.

An estimate for the uncertainty in the absolute values of cross sections given below is about 15%.

The energy dependences of the absolute cross sections σ_I for Na^+-He, Ne, Ar and σ_C for Li^+-He, Ne, and Ar collisions are plotted, as an example, in Figs. 1 and 2. It appears that the discrepancies between our results and those of other authors [2,3] are considerable. The reasons for this are the experimental difficulties mentioned above. For example, we determined that in Na^+-Ne collisions about 25% of the target gas ions have energies higher than 40 eV, and about 15% of the free electrons have energies above 30-35 eV.

The interpretation of our results by plotting schematic correlation diagrams of diabatic terms of the system of colliding particles [4] and the use of model representations [5,6] has made it possible to express certain conclusions about the mechanisms of the relevant processes. It was found that in Li^+-Ar collisions, an electron is captured mainly into ground state of the lithium atom $Li(^2S)$, at an internuclear distance R~1.5 a.u. For the Li^+-Ne pair, the charge transfer process is realized through an intermediate state Li^+-$Ne(2p^5\ ^3S)$ at relatively large internuclear distances R.

A comparison of our data for Li^+-He collisions with the cross sections for emission of the resonance line of lithium atoms (transition $^2P \rightarrow {}^2S$, λ=670.8 nm), reported in [7], shows that σ_C includes a considerable (~50%) contribution from the cross section for electron capture by an excited state of the lithium atom, Li(2p).

The contributions of the various channels to the total cross sections σ_I were estimated to define the mechanism of the ionization process. For direct ionization channels such contribution was estimated by calculations of partial cross sections using a procedure described in ref. [6]. For an estimate of the contributions of molecular and atomic autoionization channels [8] experimental data for the spectrum of free electrons were used. We found that for the Na^+-Ar pair the direct ionization channel is dominant, whereas for the Na^+-Ne pair the process of atomic autoionization of neon is about 30% and direct ionization about 10%. In the case of Na^+-He pair the atomic autoionization channel of helium is the main one.

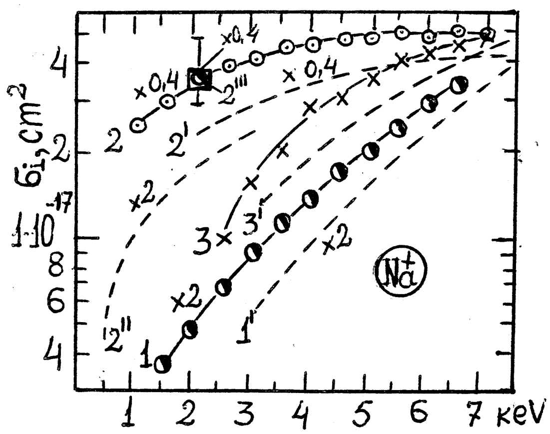

Figure 1: Ionization **(Na^+-He)** - *1)* our results, *1')* [2]; **(Na^+-Ne)** - *2)* our results, *2')* [2], *2'')* [3] *2''')* [10]; **(Na^+-Ar)** - *3)* our results, *3')* [2].

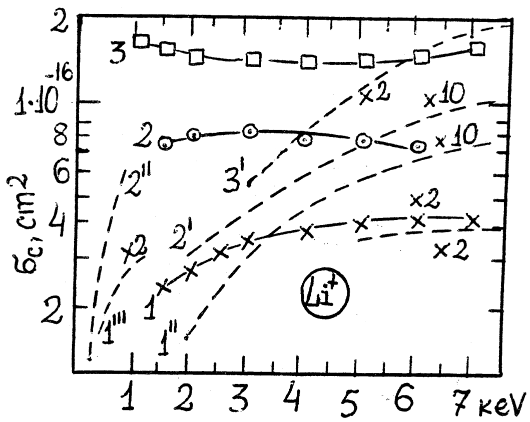

Figure 2: Charge Transfer: **(Li^+-He)** - *1)* our results, *1')* [11], *1'')* [2], *1''')* [3]; **(Li^+-Ne)** - *2)* our results, *2')* [2], *2''* [3]; **(Li^+-Ar)** - *3)* our results, *3')* [2].

In Fig. 3, our experimental (curves 1, 4) and calculated data (curve 3) of stripping cross sections for the collisions K^+-He, Ne are compared with experimental data for the excitation cross sections of ten autoionization states of K^+ ions for the collision K^+-He reported in ref. [9] (curve 2) in arbitrary units. The comparison shows that the main realization of the stripping process, at least for the K^+-He pair in the investigated energy region, is connected with the direct ionization mechanism.

The energy and angular dependences of the differential cross sections of elastic scattering were defined for various pairs of particles. As an example, in Fig. 4 our results for K^+-H_2, N_2, Ar pairs are presented at an energy E=2keV. We use reduced coordinates: $\rho(\tau)=\theta\sin\theta\ d\sigma/d\Omega$

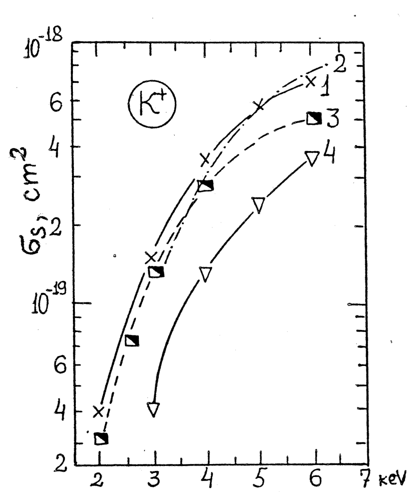

Figure 3: Stripping: **(K^+-He)** - *1)* our results, *2)* [9], *3)* [6]; **(K^+-Ne)** - *4)* our results.

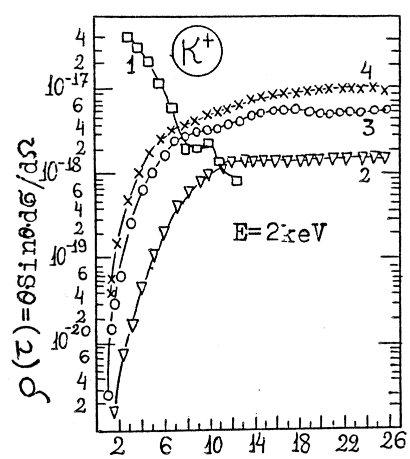

Figure 4: Differential Cross Sections: **(K^+-Ar)** - *1)* elastic scattering; **(K^+-H_2)** - *2*; **(K^+-N_2)** - *3*; **(K^+-Ar)** - *4)* charge transfer.

(impact parameter), and τ=Eθ (reduced angle), where E, θ are the collision energy and scattering angle in the mass-center system. For definite absolute values, the total charge transfer cross sections (restored from differential cross sections) were normalized to the one for the K^+-Ar collision, which was measured by the condenser method. It appears that the angular dependence of the charge transfer cross sections has a threshold behavior (curves 2, 3, 4). The abrupt decrease of the elastic scattering cross section at τ~5-7 keV is due to reaching the internuclear distance R at which the inelastic processes get excited. Our results indicate that the charge transfer processes in these collisions are connected with mechanisms of the pseudo-crossing of the quasimolecular potential energy terms of corresponding states. Because of the significance of the mass-ratio, the internuclear distance in the region of nonadiabatic collisions for K^+-H_2 is smaller. That is why for this pair the absolute cross sections σ_C are smaller for K^+-N_2, Ar pairs, as shown by our results.

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