CROSS SECTIONS AND SINGULARITIES OF RESONANT CHARGE EXCHANGE OF CALCIUM, STRONTIUM, AND BARIUM IONS

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A new procedure is proposed for measuring the total cross sections for the charge exchange of ions with atoms. The energy dependences of the resonant charge-exchange cross sections of the ions Ca^+, Sr^+, and Ba^+ are investigated in the range from 6 to 1000 eV, where regular oscillations are observed.

We report here data obtained for the first time on resonant charge exchange of alkaline-earth element ions. To investigate this process, we used original apparatus that offers appreciable advantages over the known methods. These advantages are particularly manifest at low interacting-particle energies. The idea of our measurement method is to use a quadrupole capacitor as a detector of the slow charge-exchange ions (see Fig. 1).

A cylindrical ion beam (2) properly shaped by an ion-optical system (1) passes along the axis of a quadrupole capacitor and enters a deep Faraday cylinder (4). A beam of neutral atoms (5), shaped by a diffusion source (6), passes between the capacitor electrodes in a direction perpendicular to the ion beam. The beam interaction takes place in the region of their intersection. A small constant potential difference is applied to the electrodes of the quadrupole in such a way that the potentials of two neighboring electrodes are equal but opposite. This produces in the quadrupole space an electric field that is transverse to the ion beam and has a hyperbolic, axially symmetrical distribution. Since there is practically no field along and near the capacitor axis, it is possible to pass through the capacitor a beam of ions with very low energy, on the order of several electron volts.

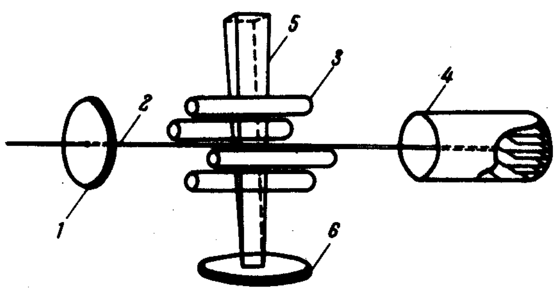

Fig. 1. Arrangement of the charge-exchange ion detector in the beam-interaction region.

On the other hand, the slow charge-exchange ions produced by the collisions, as well as the electrons and ions produced as a result of the accompanying inelastic processes, are extracted by the electric field that increases in the direction towards the electrodes of the quadrupole, and are gathered by the corresponding electrode pairs. Thus, the method described above foe detecting charge-exchange ions combines the advantages of the parallel-plate capacitor method and of the cylinder method, and eliminates the shortcomings inherent in each individual method [1].

Measurements of the resonant charge exchange of the Ca^+, Sr^+, and Ba^+ ions were made in the kinetic-energy range from 1000 to 6 eV at a primary-ion beam current $(2 - 8)\times10^{-8}$ A and at an energy scatter 2 - eV (at half-height of the distribution function). The particle concentration in the atom beam, at the point of intersection, was approximately 10^{11} cm^{-3}. The absolute cross sections were obtained by calibrating the measuring apparatus against the known electron-impact ionization cross sections of the atoms of the investigated elements [2]. The error in the determination of the absolute values of the charge-exchange cross sections was 30%, whereas the error in the measurement of the relative energy dependence of the probability of the process was 2 - 6%.

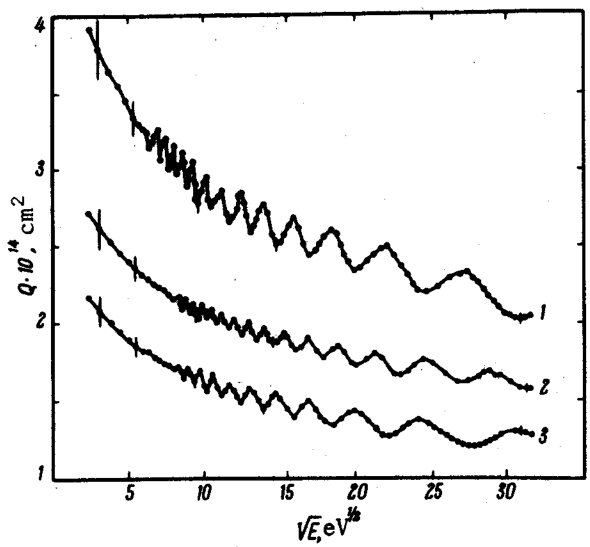

Fig. 2. Effective resonant charge-exchange cross sections: 1) Ba^+ + Ba, 2) Sr^+ + Sr, 3) Ca^+ + Ca.

The experimental results are shown in Fig. 2. We see that the effective cross section of the resonant charge exchange increases on the whole monotonically with decreasing interaction energy, and reaches at an ion energy 6 eV values 2.2×10^{-14} cm^2, 2.7×10^{-14} cm^2, and 3.9×10^{-14} cm^2 for Ca^+, Sr^+, and Ba^+, respectively.

Another important result of our investigation is the observation of a clear-cut oscillatory structure of the energy dependence of the cross section of the process for all three pairs of the interacting particles. A remarkable feature of this structure is its exceedingly high regularity, namely, all its numerous maxima are equidistant when plotted against the reciprocal of the velocity (see Fig. 3).

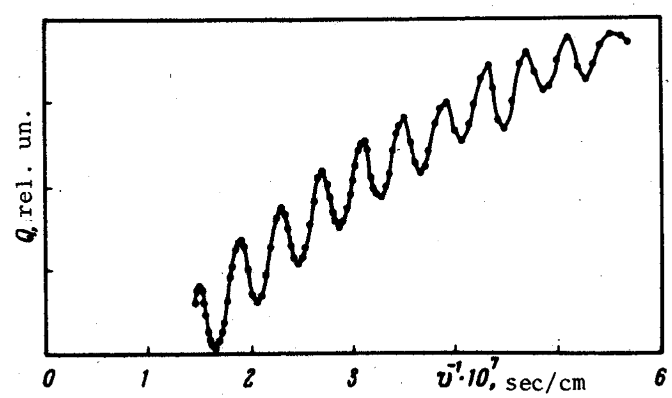

Fig. 3. Cross section of resonant charge exchange of the Ca^+ ion as a function of the reciprocal velocity.

A preliminary analysis of the fine structure of the cross sections of the resonant charge exchange of the investigated ions has shown that the oscillating part of the energy dependence of the cross section (which is the difference between the experimental curve and its smoothly-varying component) can be described by a relatively simple analytic formula of the type

$$Q_{osc} = A(v)\cos(\beta v^{-1} - \delta),$$

where v is the velocity of the incident ion, A(v) is the amplitude, β is the frequency, and δ is the phase constant of the oscillations. The values of all the parameters in each concrete case can be calculated here with sufficient accuracy on the basis of the obtained experimental data.

A complete analysis of the measurement procedure, a detailed discussion of the results obtained on the resonant charge exchange of ions of alkaline-earth metal elements, and the interpretation of the oscillatory structure of the energy dependences of the process will be given in subsequent papers.

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[2] L. A. Vainshtein, V. I. Ochkur, V. I. Rakhovskii, and A. M. Stepanov, Zh. Eksp. Teor. Fiz. 61, 511 (1971) [Sov. Phys.-JETP 34, 271 (1972)].