A MODEL OF DOUBLE NONRESONANT CHARGE EXCHANGE

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A model of double nonresonant charge exchange at intermediate and low velocities is considered, in which the probability of the process is given by the square of the single charge exchange probability. The cross sections obtained with the model are in good agreement with the experimental data.

A theoretical investigation of processes in which the particles become redistributed following collisions of heavy atomic systems, especially processes in which more than one particle takes part in the transitions, is greatly hindered by the lack of usable multiparticle wave functions (or good asymptotic expressions for them), by the ambiguity of the interaction potential, and by the non-orthogonality of the initial and final states. Nonetheless, in view of the great interest attaching to processes of double charge exchange, theoretical estimates of their cross sections are desirable.

We wish to call attention in this paper to the connection between double and single nonresonant charge exchange.

We consider a reaction of the type

$$A^+ + B \to A^- + B^{2+} + \Delta E \qquad (1)$$

at medium and low velocities. Such processes were investigated experimentally in [1,2]. We assume that the energy of the interaction between the transferred electrons in the velocity region under consideration is small relative to the remaining part of the Hamiltonian, so that the nonstationary Schrödinger equation breaks up in the adiabatic approximation into two equations, each of which describes the motion of one of the active electrons. The transition probability of the electron pair can then be represented in the form of a product of the transition probabilities of the individual electrons. An analogous approximation was used by Mittleman [3] in the resonant case and at high velocities.

We shall henceforth assume that the single-electron probabilities of the transitions are equal to each other and represent the probability $P_1(\rho, v)$ of the process

$$A^+ + B^+ \to A + B^{2+} + \Delta E. \qquad (2)$$

We thus obtain for the probability of the double charge exchange

$$P_2(\rho, v) = P_1^2(\rho, v), \qquad (3)$$

where ρ is the impact parameter and v is the relative velocity. Such a representation is reasonable at large values of v. We can, however, expect this method to be effective at medium and not too low energies.

In the velocity region under consideration, the probability $P_1(\rho, v)$ can be determined by the method of Rapp and Francis [4], and is given by

$$P_1(\rho, v) = fP_0(\rho, v)\,\mathrm{sech}^2\left[\frac{|\Delta E|}{v}\rho\left(\frac{\pi}{2x}\right)^{1/2}\right]. \qquad (4)$$

Here $x = \gamma\rho$, $\rho = \sqrt{2I}$, I is the smallest of the binding energies of the active electron in reaction (3), and $|\Delta E|$ is the difference between the binding energies of the same electron in the final and initial states,

$$P_0(\rho, v) = \sin^2\Gamma(\rho, v),$$

$$\Gamma(\rho, v) = \left(\frac{2\pi}{\gamma}\right)^{1/2}\frac{I\rho^{3/2}}{v}\left(1+\frac{1}{x}\right)e^{-x}. \qquad (5)$$

The statistical factor f of the reaction (3) is determined in accordance with the Wigner-Witmer rules [5]. All these expressions were obtained under the condition that $x \gg 1$.

Integrating $P_2(\rho, v)$ with respect to the impact parameters, the azimuthal angle, and replacing the rapidly-oscillating function $\sin^4\Gamma$ by its mean value, we obtain for the cross section of double nonresonant charge exchange

$$Q_2(v) = f^2 Q_0 I_2(u_1), \qquad (6)$$

where

$$u_1 = u(\rho_1), \quad u(\rho) = \frac{|\Delta E|}{v}\rho\left(\frac{\pi}{2x}\right)^{1/2};$$

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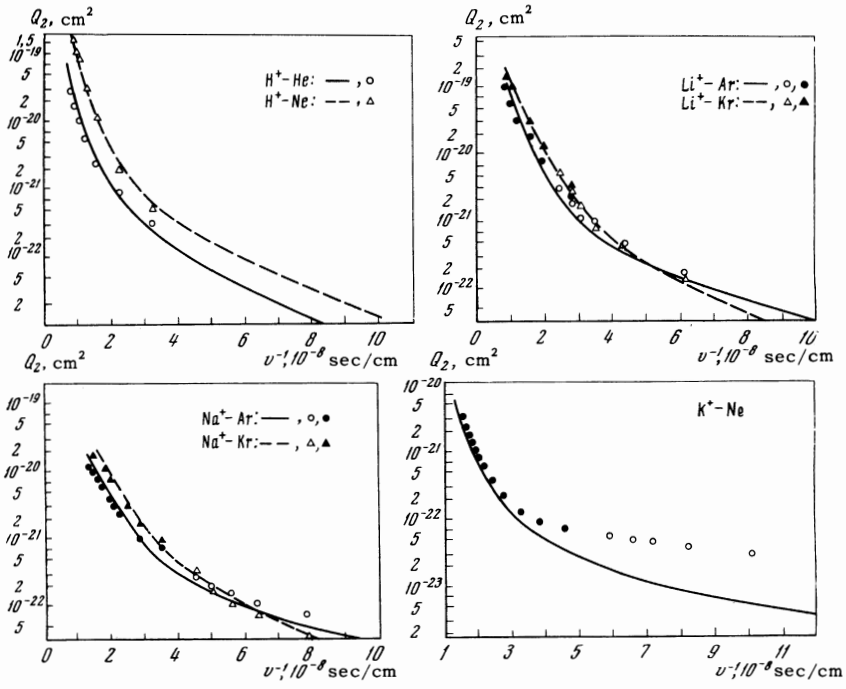

FIG. 1. Cross sections of double charge exchange of singly charged positive ions in inert gases. Curves – results of present paper, point – experimental data: light – from [1], black – from [2].

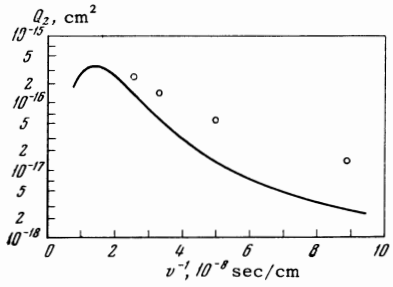

FIG. 2. Cross section of the reaction $Kr^{2+} + Ar \rightarrow Kr + Ar^{2+}$; points – experimental data from [7].

$$Q_0 = \pi\rho_1^2/2;$$

$$I_2(u_1) = \frac{3}{u_1^4}\int_0^{u_1} u^3 \operatorname{sech}^4 u\, du. \qquad (7)$$

The critical impact parameter ρ_1 is determined from the condition $\Gamma(\rho, \gamma) = \pi/6$. Then the connection between the parameters u_1 and ρ_1, on the one hand, and the relative velocity v on the other, is that determined by Lee and Hasted [6]. The integral $I_2(u_1)$ was calculated numerically.

Using the described model, we calculated the cross sections of the reaction (1) for A → H, Li, Na, K and B → He, Ne, Ar, and Kr. The results, which are shown in Fig. 1, were compared with the experimental data [1,2]. As seen from the figure, the experimentally observed inflection in the cross sections of these reactions, connected with the violation of the adiabaticity criterion, is correctly represented within the framework of the proposed model. The discrepancy at low velocities is connected with the fact that the impact-parameter method is not applicable in this region.

An estimate of the reaction $Kr^{2+} + Ar \rightarrow Kr + Ar^{2+}$ [7] also shows (see Fig. 2) that the proposed model gives the correct order of magnitude of the cross section.

We can thus conclude that the employed model represents correctly the physical features of the process and is sufficiently effective for an estimate of the cross sections of double nonresonant charge exchange.

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