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OSCILLATION OF THE CHARGE EXCHANGE CROSS SECTIONS IN THE Na^+-Ne SYSTEM

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In an earlier investigation [1] we observed the structure of the energy dependence of the cross section of the process $He^{2+} + He \rightarrow He^+ + He^+$, which we ascribed to an effect connected with the intersection of the He^{2+}-He term with terms of the systems $He^+(n\ell)$ - He(1s) and He^{2+} - $He^*(1s, n\ell)$. On the basis of an analysis of the experimental data [2], a model of atomic collisions was proposed in [3] to explain the conditions for the oscillation of the dependence of the cross sections of inelastic processes on the collision energy. With the aid of this model it was possible to obtain certain information on the terms of the quasimolecule that is produced in the atomic collisions, by investigating the effective cross sections of these collisions. In this paper we continue the study of the cross sections of ion-atomic collisions in the low-energy region, where the presence of intersections or of close approaches of the terms of the quasimolecule can become manifest in the form of a structure on the cross sections of the inelastic processes.

The effective cross section of the charge exchange process

$$Na^+ + Ne \rightarrow Na + Ne^+, \quad \Delta E = -16.42 \text{ eV} \tag{1}$$

was investigated in the interval of kinetic energies of the Na^+ ion $400 \leq T \leq 2500$ eV. To find the effective cross section σ of the process (1) by the method described in [1], we measured the summary cross sections σ_{Ne^+} for the formation of Ne^+ ions in process (1) in the ionization process

$$Na^+ + Ne \rightarrow Na^+ + Ne^+ + e \tag{2}$$

and the cross section σ_e for the production of free electrons in Na^+-Ne collisions. Since the potentials for the ionization of Na^+ (47.5 eV) and of the double ionization of Ne (62.5 eV) greatly exceed the ionization potential of Ne (21.5 eV), the main contribution to the cross section σ_e is made in the investigated interval of T by the process (2). Therefore the charge exchange cross section (1) can be defined as the difference $\sigma = \sigma_{Ne^+} - \sigma_e$. Principal attention is paid in the present paper to the accuracy with which the function $\sigma(T)$ is determined. Figure 1 shows the obtained $\sigma(T)$ dependence. The errors (mean arithmetic deviations) in the determination of the relative cross sections $\sigma(T)$ are indicated in Fig. 1 in the form of bars. The absolute value of the cross section at T = 2000 eV is estimated by us at 1×10^{-17} cm^2 (±40%).

As seen from Fig. 1, the cross section σ of the charge exchange (1) oscillates as a function of the energy T. A plot of the dependence of the cross section on the reciprocal collision velocity v^{-1} reveals, within the limits of

the accuracy with which the positions of the extrema are determined, that the maxima are equidistant in terms of v^{-1}; the average distance between the maxima is $\Delta v^{-1} \approx 1.3 \times 10^{-8}$ sec/cm.

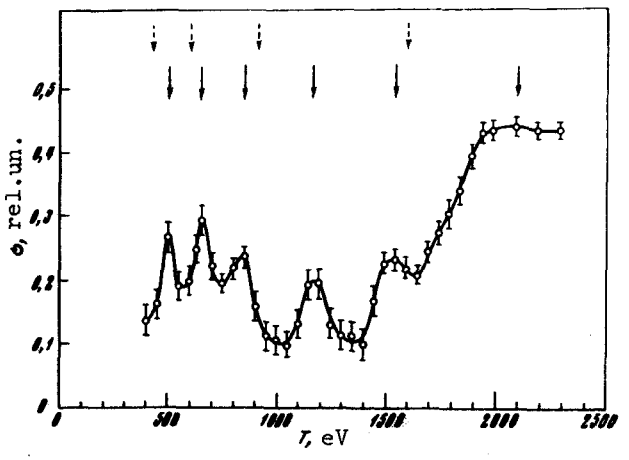

Fig. 1. Effective charge exchange cross section.

Oscillations of the cross section for the resonant lines of the Ne atom (736 and 744 Å) were observed in [4] for the processes

$$Na^+ + Ne \to Na^+ + Ne^*, \quad \Delta E = -16.85 \text{ eV}; -16.67 \text{ eV} \qquad (3)$$

in the Na^+ ion energy interval $0.2 \leq T \leq 11$ keV. The maxima of the cross sections are equidistant in terms of the coordinates v^{-1}; the distance between the maxima is $\Delta v^{-1} \approx 2.6 \times 10^{-8}$ sec/cm. The $NaNe^+$ quasimolecule terms corresponding to the system $Na\text{-}Ne^+$ and $Na^+\text{-}Ne^*$, where Ne* represents the Ne atoms in the states $2p^5(^2P^0_{1/2})3s$ and $2P^5(^2P^0_{3/2})3s$, at large internuclear distances, are close to each other; the difference between these terms at $R \to \infty$ amounts to 0.21 and 0.46 eV. Therefore, assuming nonadiabatic development of these terms after they become populated in (1) and (3), and in accordance with the model of [3], it is predicted in [4] that the cross section of the charge exchange (1) oscillates in counterphase to the oscillation of the cross section (3).

A comparison of the excitation cross section (3) from [4] with the cross section of (1) obtained by us points to the presence of regular oscillations in the cross sections of the channels (1) and (3) in the same collision-energy interval. The solid arrows of the lower row in Fig. 1 mark the positions of the maxima of the cross section of the charge exchange (1), while the dashed arrows of the upper row mark the positions of the maxima of the excitation cross section (3) from [4]. We see that the maxima of the cross section (1) are shifted relative to the maxima of (3). However, there is an essential difference between the course of the two cross sections: the frequency of the oscillations of the cross section of the charge exchange (1) is approximately double the frequency of the oscillations of the cross section for the excitation (3).

The results of the present paper point, within the limits of measurement accuracy, to the absence of regular oscillations in the cross sections of the other channels which open up in Na^+-Ne collisions in our energy interval. For example, with large accuracy, the cross section σ_e varies monotonically in the investigated interval of T. Therefore, in spite of the frequency difference, the oscillations of the cross sections of channels (1) and (3) are interrelated.

The difference between the frequencies of the cross sections (1) and (3) can be attributed to the interaction of the term of the system $Na\text{-}Ne^+$ at large R with two terms of $Na^+\text{-}Ne^*$. Let us consider the scheme (Fig. 2) of the terms of the quasimolecule produced upon collision of two atoms. Let the term E_0 of the elastic channel (initial system) intersect at R_0 the terms E_1, E_2, and E_3 of the inelastic channels, the term E_1 intersecting the terms E_2 and E_3 at R_1 and R_2. For the total probability W_i ($i = 1, 2, 3$) of finding the system after the collision in the state with term E_i we can derive the expressions:

$$W_1 = |a_3(R_0)|^2(1-p_1)^2 + |a_1(R_0)|^2 p_1^2 + 2\mathrm{Re}\, a_1(R_0) a_3(R_0) p_1(1-p_1) \times \cos[\phi_1(R_1) - \phi_3(R_1)], \quad (4)$$

$$W_2 = |a_3(R_0)|^2 p_1^2(1-p_2)^2 + |a_1(R_0)|^2(1-p_1)^2(1-p_2)^2 + |a_2(R_0)|^2 p_2^2 + 2\mathrm{Re}\, a_3(R_0) a_1(R_0) p_1(1-p_1)(1-p_2)^2 \cos[\phi_1(R_1) - \phi_3(R_1)] + 2\mathrm{Re}\, a_2(R_0) a_3(R_0) p_1 p_2(1-p_2) \cos[\phi_2(R_2) - \phi_3(R_2)] + 2\mathrm{Re}\, a_1(R_0) a_2(R_0) p_2(1-p_1)(1-p_2) \cos[\phi_1(R_1) + \phi_2(R_2) + \phi_3(R_2) - \phi_3(R_1)], \quad (5)$$

$$W_3 = |a_3(R_0)|^2 p_1^2 p_2^2 + |a_1(R_0)|^2(1-p_1)^2 + |a_2(R_0)|^2(1-p_2)^2 + 2\mathrm{Re}\, a_1(R_0) a_3(R_0) p_1 p_2(1-p_1) \cos[\phi_1(R_1) - \phi_3(R_1)] + 2\mathrm{Re}\, a_2(R_0) a_3(R_0) p_1 p_2(1-p_2) \cos[\phi_2(R_2) - \phi_3(R_2)] + 2\mathrm{Re}\, a_1(R_0) a_2(R_0)(1-p_1)(1-p_2) \cos[\phi_1(R_1) + \phi_2(R_2) + \phi_3(R_2) - \phi_3(R_1)], \quad (6)$$

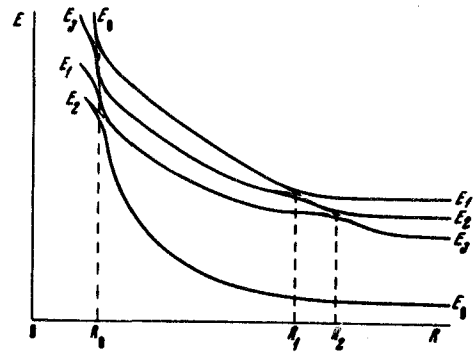

Fig. 2. Term scheme of the quasimolecule.

where $a_i(R_0)$ are the initial amplitudes of the population of the terms E_i; p_1 and p_2 are the probabilities of the (Landau-Zener) transition between the terms at R_1 and R_2; $\phi_i(R)$ is the change of the phase in the interval $R - R_0$. Since the arguments of the cosines in (4), (5), and (6) do not depend on the impact parameter, the corresponding effective cross sections will oscillate in accordance with the same laws. The probability W_3 corresponds in our case to the probability of the charge exchange (1), while W_1 corresponds to the probability of excitation of the 736-Å line in the process (3). It is seen from (4), (5), and (6) that as a result of the intersection of the terms of the three inelastic channels at R_1, $R_2 > R_0$, the cross sections of these channels oscillate at resonant frequencies. For example, the oscillation frequency of W_3 can exceed the frequency of W_1.

The connection between the cross sections of (1) and (3) confirms the nonadiabatic behavior of the terms of $Na-Ne^+$ and Na^+-Ne^* at large R, and makes it possible to estimate the excitation cross sections of (3) from the known absolute values of the cross section of (1).

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SCATTERING OF 4-MeV NEUTRONS AT ANGLES CLOSE TO 180°

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Measurements were made of the elastic scattering of a polarized beam of