1. INTRODUCTION

The ionization processes occurring during the collision of two negative ions are of considerable interest in connection with the problem of nuclear plasma heating by neutral atomic hydrogen beams. It is convenient to generate the beams of fast neutral atoms by accelerating and neutralizing negative ions in view of the relatively large cross section of their neutralization at targets. However, the collisions of negative ions in high-intensity beams, which occur due to the spread in their velocities, effectively suppress the intensity of such beams. For high collision energies, the cross sections of the electron detachment are calculated by the method of close coupling of states. The calculated cross sections are in good agreement with the results of experimental measurements made for the $H^- + H^-$ collision.

In this paper, atomic units of measurements are used.

2. DETACHMENT OF ELECTRONS FOR HIGH COLLISION VELOCITIES. DYNAMIC DETACHMENT

All the three reactions, (A), (B), and (AB), occur predominantly at large distances $R$ between nuclei, when the Coulomb repulsion between weakly bound electrons of the negative ions play the major role. For large $R$, this interaction can be expanded into a series in reciprocal powers of $R$:

\[ A^- + B^- = \begin{cases} 
A + B^+ + e, & \text{(A)} \\
A^- + B + e, & \text{(B)} \\
A + B + 2e, & \text{(AB)}
\end{cases} \]

whose probabilities strongly compete with one another. For this reason, we calculate the cross sections of these processes simultaneously by solving a single wave equation. Reactions (A), (B), and (AB) will be investigated by us for the following three collisions: $H^- + H^-$, $H^- + Cs^-$, and $Cs^- + Cs^-$. For high collision velocities, processes (A), (B), and (AB) occur as a result of direct transfer of a part of the kinetic energy of the nuclei to the electrons. In this limit, the cross sections are calculated in the dynamic approximation. For low velocities, the energy exchange between electrons and nuclei has a low probability, and another mechanism becomes effective. In view of the smallness of the binding energy of negative ions and their repulsion, several channels of autoionization decay become effective simultaneously for low velocities. When two ions approach each other, the electronic energy level rises and intersects the boundary of the continuum even for very large distances between the nuclei. As in the dynamic approximation, the Auger decays of the autoionization states formed in this process lead to considerable values of the cross sections of the above reactions.

In this paper, atomic units of measurements are used.
DETACHMENT OF ELECTRONS DURING THE COLLISION OF TWO NEGATIVE IONS

In monograph [6], coefficient $B$ was determined by joining the first term in formula (3) with the wave function of the $\mathrm{H}^-$ ion determined by Chandrasekhar [10] with three variable parameters; it was found that $B_{\mathrm{H}^-} = 1.183$. In our earlier publications [7, 8], we considered the wave equation satisfied by function (3). It was found by fitting the potential appearing in this equation to the static potential of a neutral hydrogen atom in the ground state that $\beta_{\mathrm{H}^-} = 2.66$ for $\mathrm{H}^-$. Using formula (3) which defines coefficient $B$, we obtain $B_{\mathrm{H}^-} = 1.145$.

The relative difference between the values of the coefficient $B_{\mathrm{H}^-}$ obtained in [6] and in [7, 8] amounts to only 3.3%. For $\mathrm{Cs}^-$, the same approximation that was used earlier [7, 8] for $\mathrm{H}^-$ now yields $\beta_{\mathrm{Cs}^-} = 1.45$ (see also [11]), which gives $B_{\mathrm{Cs}^-} = 1.22$.

In view of the smallness of the binding energy for negative ions, the cross section for all the three reactions are large, and we therefore take into account only the transitions of weakly bound electrons. In this case, the wave functions of the complete set of the states of the system formed by two negative ions are given by

$$
\psi_a^{(-)}(r_1, r_2) = \left[ \frac{1}{n^2 \pi r^2} \right]^{1/2} e^{-\beta r} e^{-\gamma \rho},
$$

where $\psi_a^{(-)}$ are the wave functions of weakly bound electrons and $\psi_a^{(-)}$ are the wave functions of neutral atoms with an electron in the continuum corresponding to energy $\varepsilon$. Expression (5) is the wave function of the system formed by two negative ions, i.e., the wave function of the initial state; expressions (6) and (7) describe the states in which the electron of one of the ions, $\mathrm{A}^-$ or $\mathrm{B}^-$, is detached and belongs to the continuum, while expression (8) describes the state with two detached electrons.

The complete wave function of the system is given by

$$
\psi(a, b)(r_1, r_2) = a_0(t) \psi_a^{(-)}(r_1, r_2) \psi_b^{(-)}(r_2) \exp[-i(\varepsilon_a + \varepsilon_b)t] + \int a(t, \varepsilon) \psi_a^{(-)}(r_1) \psi_b^{(-)}(r_2) \exp[-i(\varepsilon_b + \varepsilon)t] d\varepsilon
$$

$$
+ \int b(t, \varepsilon) \psi_a^{(-)}(r_1) \psi_b^{(-)}(r_2) \exp[-i(\varepsilon_a + \varepsilon)t] d\varepsilon
$$

where $\psi_a^{(-)}$ are the wave functions of weakly bound electrons and $\psi_a^{(-)}$ are the wave functions of neutral atoms with an electron in the continuum corresponding to energy $\varepsilon$.

The binding energies of the ions $\mathrm{H}^-$ and $\mathrm{Cs}^-$ under investigation are given by

$$
\varepsilon_{\mathrm{H}^-} = -0.75421 \text{ eV} \quad (\gamma_{\mathrm{H}^-} = 0.23544),
$$

$$
\varepsilon_{\mathrm{Cs}^-} = -0.4716 \text{ eV} \quad (\gamma_{\mathrm{Cs}^-} = 0.1862).
$$