Towards prediction of the rates of antihydrogen positive ion production in antihydrogen-excited positronium reaction

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Synopsis We present the 4-body calculation of the antihydrogen-positronium scattering aiming at the prediction of cross sections for the production of antihydrogen positive ions. The latter are expected to be a useful source of ultra-cold atoms for the test of matter-antimatter gravity. We convert the Schrödinger equation to a set of coupled integro-differential equations that involve intermediate states and are solved using the compact finite difference method. We will present the investigation of the rearrangement reaction between the ground-state antihydrogen atom and the excited positronium.

Antihydrogen positive ion ($\bar{\mathrm{H}}^+$) consists of an antiproton ($\bar{\mathrm{p}}$) and two positrons (e^+). $\bar{\mathrm{H}}^+$ may be manipulated by electric field and be used in studies of particle physics and atomic physics. $\bar{\mathrm{H}}^+$ ions are expected to be useful intermediates in the production of ultra-cold antihydrogen atoms which have been expected to be a good probe for the gravity between matter and antimatter [1, 2]. It would be prepared by sympathetic cooling of $\bar{\mathrm{H}}^+$ with Be^+ ions and the subsequent photodetatchment. $\bar{\mathrm{H}}^+$ can also be utilized to develop an energy-tunable antihydrogen beam that will be used in atomic collision experiments.

Reaction between antihydrogen atom ($\bar{\mathrm{H}} = \bar{\mathrm{p}}\mathrm{e}^+$) and positronium ($\mathrm{Ps} = \mathrm{e}^+\mathrm{e}^-$) has been featured recently as one of the promising production schemes of $\bar{\mathrm{H}}^+$. A channel of $\bar{\mathrm{H}}^+$ production,

$$\bar{\mathrm{H}}\,(1\mathrm{s}) + \mathrm{Ps}\,(1\mathrm{s}) \to \bar{\mathrm{H}}^+ + \mathrm{e}^-, \tag{1}$$

opens at the collision energy 6.05 eV. A reaction between $\bar{\mathrm{H}}\,(1\mathrm{s})$ and the second excited Ps ($n = 3$) is also promising because the positron transfer to $\bar{\mathrm{H}}$ from Ps ($n = 3$),

$$\bar{\mathrm{H}}\,(1\mathrm{s}) + \mathrm{Ps}\,(n = 3) \to \bar{\mathrm{H}}^+ + \mathrm{e}^-, \tag{2}$$

can occur at the collision energy 1.7 meV. The rearrangement reactions (1) and (2) compete with several inelastic reactions of Ps (de-)excitation and require rigorous theoretical treatment.

Aiming at the prediction of cross sections in the reaction (2), the present work extends a coupled rearrangement channel scattering calculation method which has been adopted to elastic scattering between $\bar{\mathrm{H}}$ and H [3]. A total scattering wavefuntion Ψ is written as

$$\Psi = \sum_{\upsilon} a_{\upsilon}\Phi_{\upsilon} + \sum_{c} \psi_c, \tag{3}$$

where the first summation with constants $\{a_\upsilon\}$ describes an intermediate state of the scattering state and ψ_c describes the initial and final states c. A set of $\{\Phi_\upsilon\}$ is constructed by a Gaussian expansion method (GEM) [4] to satisfy $\langle\Phi_{\upsilon'}|\Phi_\upsilon\rangle = \delta_{\upsilon'\upsilon}$. The Schrödinger equation with total 4-body Hamiltonian H, $H\Psi = E\Psi$, is converted to a set of coupled integro-differential equations under proper boundary conditions on asymptotic behavior of scattering wavefunction. We have solved the set of coupled equations by the compact finite difference method and have obtained the multi-channel S-matrix as a function of collision energy. Cross sections of the reactions (1) and (2) are extracted from the S-matrices as well as the cross sections of the competing inelastic reactions of Ps (de-)excitation.

We have found that the cross section of reaction (1) is consistent in magnitude with the previous calculation [5] by close-coupling method. We will present the formulation, benchmark calculations, and investigation on the reaction (2).

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