The 4-body structure and scattering calculations for the antihydrogen - positronium system: aiding the experiments comparing matter and antimatter.

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We present the 4-body calculations of the binding, resonant, and collisional properties of the antihydrogen-positronium system $\bar{H} - Ps$. The binding energy, the life-times of the resonant states, and the collisional cross sections are calculated and discussed. In particular, we have calculated the cross sections for the rearrangement collisions that produce antihydrogen ions $\bar{H} + Ps \rightarrow \bar{H}^+ + e$. These collisions are essential for the ongoing GBAR experiments at CERN, in that they enter the chain of reactions generating the ultra-cold antihydrogen atoms. There are no experimental data for these cross sections. High accuracy theoretical results are hence important to aid the experiments. To describe the structure of the $\bar{H} - Ps$ system we apply the 4-body variational approach based on the Gaussian Expansion Method (GEM) [2]. The distinctive novel feature of our approach (as compared to the previous calculations on the conjugated system $H - Ps$, e.g. [2,3]) is the simultaneous use of several Jacobi sets of coordinates in the variational expansion of the multi-channel wave functions. This allows an efficient and rigorous treatment of the scattering cross sections and alleviates the problem of linear dependencies. The binding energy is calculated and discussed in terms of the contributions from various arrangement channels, the accuracy is on the order of micro-Hartrees. Channel analysis helps to converge the binding energy and throws light on the structure and collisional properties of the system. The structural information is extracted from the four-body wavefunctions. We present the 1- and 2-dimensional, radial and angular probability densities that illustrate the spatial distribution of the particles and their correlations. This helps to understand the structure and dynamics of the system, in particular the change of the $\bar{H}^+$ upon binding of an electron, and the coexistence of the atomic and molecular features of $\bar{H}Ps$. The resonant states and their life-times are calculated variationally using GEM in conjunction with the Complex Coordinate Method (CCM). The energies and widths of the resonances are analysed with respect to the channel composition of the resonant wave functions. For the first time, we present the *partial* life-times for the decay of resonances above the $Ps(n = 2)$ excitation threshold. Based on the variational description of the four-body system, we apply the coupled rearrangement channels method to calculate the elastic, inelastic and rearrangement cross sections for $\bar{H} - Ps$ collisions. The outer part of the total wave function is made to satisfy the scattering boundary conditions appropriate for the collisional fragments and is matched to the variationally obtained inner part. This is facilitated by the use of several Jacobi sets of coordinates (corresponding to various arrangement channels) in the description of the multi-channel structure of the wave function [4]. The scattering matrix S and the cross sections are obtained from the coupled, non-local integro-differential equations that explicitly couple the collisional channels of interest. We include and couple all 7 open channels

up to and beyond the $\bar{H}^+ + e$ threshold. We report the $\bar{H}^+$ production cross sections for the ground and excited $Ps(n = 1, 2, 3)$ states of the $\bar{H} + Ps \rightarrow \bar{H}^+ + e$ reaction. We also report the cross sections for all other processes that compete with the $\bar{H}^+$ outcome. The accuracy of the cross sections is reported in terms of the unitarity of the S matrix.

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