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Resonance states in a cold collision between an antihydrogen atom and a hydrogen atom/ion

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An antihydrogen atom for a precise spectroscopy and a free-fall experiment is prepared in a high vacuum (~1 pPa) in a low temperature (down to a few Kelvin) and may annihilate with impurity particles: hydrogen atoms/ions, electrons and other gas atoms. Precise data of collision processes are required in the forthcoming experiments.
The collision process of the antihydrogen atom and a hydrogen atom has been a fundamental and challenging problem for both theoretical and experimental studies. The reaction process is completely different from that of two hydrogen atoms. In the former collision, rearrangement of four particles occurs; namely, a protonium (Pn) and positronium (Ps) formation channel opens. The Pn would be in highly excited states due to energy matching between the initial and final states. The Pn deexcites to lower energetic states giving excess energy to Ps. The motion of the nuclei strongly affects the lepton motions. However, many works have adopted adiabatic methods in which the motions of nuclei and light particles are separately calculated in this collision process.
In this work, we perform a non-adiabatic calculation of the resonance states near the cold collision energy between the antihydrogen atom and the hydrogen atom/ion. Oscillation Gaussian basis sets are introduced to reproduce the highly excited Pn wavefunctions up to n=30 with an accuracy of 6-digit. Near the cold collision threshold, resonance energies and widths are obtained by a complex rotation method. To reveal the resonance mechanism, proton mass dependence of resonance parameters is examined and compared with adiabatic calculations. The resonance states near the collision energy show a deviation from the adiabatic vibrational states and the widths are independent of the initial channel. It indicates that the resonance states couple with the rearrangement channels which breaks the adiabatic picture. The resonance widths are found to be broader than that of Boltzmann distribution of the experimental condition. Thus, the resonance phenomena are expected to be a good indication of temperature of an ultra cold atomic gas and to be utilized to purge the impurity particles by changing the temperature.

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