Low-Energy Scattering Properties of Ground-State and Excited-State Positronium Collisions

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Ground-state Ps collisions have been extensively studied due to growing interests in the creation of a spin-polarized Ps Bose-Einstein condensate (BEC) [1, 2]. To reach the BEC regime, experimental methods for producing Ps ensembles have been studied to achieve higher densities [3, 4]. One method for extracting information about the densities of atomic ensembles that is of recent interest for the Ps system is through the measurement of the cold-collision (clock-shift) frequency shift. One application where the clock-shift measurement has been successful in determining densities has been in the study of hydrogen ensembles to probe densities both far from and near to the BEC regime [5, 6]. In order for an experiment to probe Ps densities using the same techniques, knowledge of *s*-wave scattering lengths for ground-state excited-state atomic collisions should be well characterized, forming the motivation for this study.

The four-body Hamiltonian investigated in this study considers only the two-body Coulombic interactions between the two electrons and two positrons in the system. The spin-spin, spin-orbit and other relativistic interactions are neglected. This problem is solved using hyperspherical coordinates, which treats all fragmentation pathways on an equal footing, with the primary interest being, but not limited to, Ps bound states. The Hamiltonian is solved in a coupled electron and coupled positron spin basis in order to simplify the construction of the total wavefunction with proper anti-symmeterization requirements. Only states with zero total orbital angular momentum and positive parity are considered in this work in representing *s*-wave collisions.

From adiabatic and diabatic potential curves, *s*-wave scattering properties are investigated in the Ps(1*s*)-Ps(2*s*) elastic and inelastic channels. Spin recoupling is implemented to represent experimentally relevant spin states of each Ps atom in a two-body collision, both in coupled spin states with total spin and uncoupled spin states, specifying spin and spin projection quantum numbers for both Ps atoms. Scattering cross-sections and scattering lengths are provided for experimentally relevant uncoupled spin states. Also, an estimate of the cold-collision frequency shift per unit density for a gas of spin-polarized triplet Ps is determined.

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References

[1] I. A. Ivanov *et al.*, *Phys. Rev. Lett.,* **87**, (2001), 063201.
[2] K. M. Daily *et al.*, *Phys. Rev. A,* **91**, (2015), 012512.
[3] D. B. Cassidy *et al*., *Phys. Rev. Lett.,* **95**, (2005), 195006.
[4] D. B. Cassidy *et al.*, *Phys. Rev. Lett.,* **104**, (2010), 173401.
[5] T. C. Killian *et al*., *Phys. Rev. Lett.,* **81**, (1998), 3807.
[6] T. C. Killian *et al.*, *Phys. Rev. A,* **61**, (2000), 033611.