Many-Body Theory for Ps-Atom Scattering and Pickoff Annihilation

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A many-body theory for positronium (Ps) interaction with many-electron atoms has been developed to calculate Ps-atom scattering cross sections and pick-off annihilation rates [1]. It takes into account virtual excitations of both objects during the collision. In our approach, we confine the Ps-atom system within a hard-wall spherical cavity [2]. We use a B-spline basis to solve the Dyson equations $\left(H_0^{\pm} + \Sigma^{\pm}\right)\psi^{\pm} = \varepsilon^{\pm}\psi^{\pm}$ for the electron $(-)$ and positron (+) in the field of the target atom. Here, $H_0^{\pm}$ is the Hamiltonian of the electron or positron in the static (Hartree-Fock) field of the atom, and $\Sigma^{\pm}$ is the many-body correlation potential. The Ps eigenstates are constructed from the electron and positron states $\psi^{\pm}$ as $\Psi = \sum_{\mu,\nu} C_{\mu\nu}\,\psi_{\mu}^{-}\psi_{\nu}^{+}$ and found from $H\Psi = E\Psi$, where $H = H_0^{-} + \Sigma^{-} + H_0^{+} + \Sigma^{+} + V + \delta V$, V being the Coulomb interaction and δV the screening correction due to polarization of the atomic electrons. The boundary condition at the wall allows us to find the scattering phase shifts. From these we obtain the scattering cross section, which we compare with recent experimental data [3]. Figure 1 shows the cross section for Ar in the frozen-target approximation (i.e., without $\Sigma^{\pm}$ and δV) and with many-body-theory treatment. The origin of the disagreement with the experiment [3] is unclear, as our calculations are expected to give the cross sections with $\leq 20\%$ uncertainty.

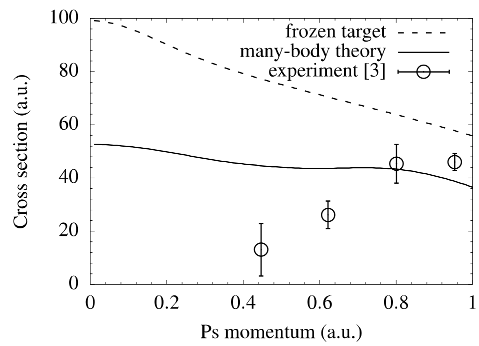

Figure 1: Cross section for elastic scattering of Ps on Ar.

The Ps wave function is also used to calculate $^1Z_{\text{eff}}$, which determines the *pickoff* annihilation rate $\lambda = 4\pi r_o^2 cn\, ^1Z_{\text{eff}}$, where r_o is the classical electron radius, c is the speed of light, and n is the gas density. Previous calculations of $^1Z_{\text{eff}}$ for noble gases [4] underestimated the experimental data [5] by a factor of 2–5. By accounting for many-body corrections to the annihilation vertex, we obtain values of $^1Z_{\text{eff}}$ in near-perfect agreement with experiment for He and Ne [1], and within 20% for Ar, Kr, and Xe.

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References

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