Low-energy positronium scattering and pickoff annihilation in atoms

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A many-body theory for positronium (Ps) interactions with many-electron atoms has been developed to calculate Ps-atom scattering cross sections and pickoff 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 $(H_0^\pm + \Sigma^\pm)\psi^\pm = \varepsilon^\pm\psi^\pm$ 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 $H = H_0^- + \Sigma^- + H_0^+ + \Sigma^+ + V + \delta V$, with V the electron-positron Coulomb interaction and δV the screening correction due to polarization of the atomic electrons. The boundary condition at the cavity 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 full many-body treatment. The origin of the disagreement with experiment is unclear, as our calculations are the most reliable to date and are expected to give the cross sections with $\leq$20% uncertainty.

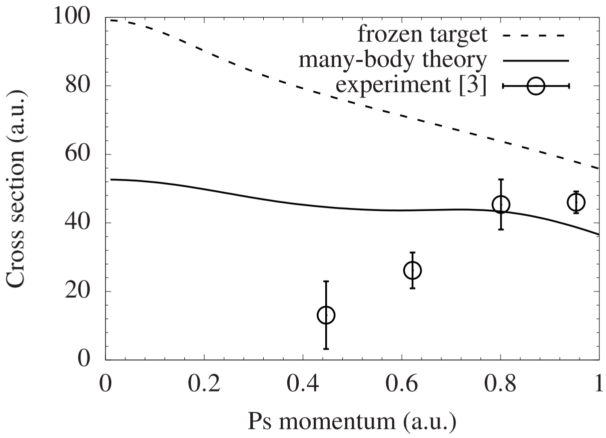

Figure 1: Cross section for elastic scattering of Ps on Ar.

The Ps wave function is also used to calculate ${}^1Z_{\rm eff}$, which determines the pickoff annihilation rate $\lambda = 4\pi r_0^2 cn{}^1Z_{\rm eff}$, where r_0 is the classical electron radius, c is the speed of light, and n is the gas number density. Previous calculations of ${}^1Z_{\rm eff}$ 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 ${}^1Z_{\rm eff}$ in near-perfect agreement with experiment for He and Ne, and within 20% for Ar, Kr, and Xe.

[1] Green D G, Swann A R and Gribakin G F 2018 *Phys. Rev. Lett.* **120** 183402

[2] Swann A R and Gribakin G F 2018 *Phys. Rev. A* **97** 012706

[3] Brawley S J *et al* 2015 *Phys. Rev. Lett.* **115** 223201

[4] Mitroy J and Ivanov I 2001 *Phys. Rev. A* **65** 012509; Mitroy J and Bromley M W J 2003 *Phys. Rev. A* **67** 034502

[5] Charlton M 1985 *Rep. Prog. Phys.* **48** 737; Saito H and Hyodo T 2006 *Phys. Rev. Lett.* **97** 253402