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Quantum suppression of antihydrogen formation in positronium-antiproton collisions[1]

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Antihydrogen ($\bar{\mathrm{H}}$) can be created in collisions of antiprotons ($\bar{p}$) with positronium (Ps) through charge-transfer reaction $\bar{p} + \mathrm{Ps}(n_i l_i) \rightarrow \bar{\mathrm{H}}(n'l') + e^-$, where the Ps state is characterised by the principal and orbital angular momentum quantum numbers n_i and l_i respectively, with n' and l' being the corresponding values for $\bar{\mathrm{H}}$. The AEgIS and GBAR Collaborations at CERN's Antiproton Decelerator plan to use this reaction to form beams of $\bar{\mathrm{H}}$ for studies of antimatter gravity. Both collaborations intend to employ laser-excited Ps as the scattering target. Theoretical simulations required for these experimental programs are based on classical trajectory methods. We used the quantum-mechanical convergent close-coupling (CCC) approach to test the validity of the classical methods. The two-centre CCC approach is a general-purpose formalism applicable to a wide range of atomic collision processes. It was originally developed for positron scattering on atomic hydrogen including Ps formation. The CCC approach is based on discretisation of the continuum and combines the expansion of the total wave function over the atomic states with that over the Ps states. Such a double expansion allows for explicit Ps formation, and allows for the distinction within the ionisation processes between Ps-formation and breakup channels. The CCC method was applied to study $\bar{\mathrm{H}}$ formation at low energies relevant to the aforementioned experimental activities. We found increases of several orders of magnitude in $\bar{\mathrm{H}}$-formation cross sections $\sigma_{\bar{\mathrm{H}}}$ when n_i was raised from 1 to 2 and 3, with the cross sections for the excited states displaying a characteristic $1/E$ dependence at low Ps kinetic energies E. Recently we extended the previous studies by considering Ps principal quantum numbers up to $n_i = 5$. We established that the dramatic increase in $\sigma_{\bar{\mathrm{H}}}$, when n_i is increased from 2 to 3 and from 1 to 2, was absent for the higher values of n_i. In the Ps kinetic energy region where the data for all n_i behave as $1/E$, there is only a factor of around 3 between the $\sigma_{\bar{\mathrm{H}}}$ for $n_i = 5$ when compared to $n_i = 3$. This is to be contrasted with the approximately factor of 30 increase between $n_i = 2$ and 3, and a several orders of magnitude enhancement in the formation of $\bar{\mathrm{H}}$ via $\bar{p}$ scattering with Ps in an $n_i = 2$ excited state over the ground state. It was concluded that quantum effects dramatically suppress the increase of $\sigma_{\bar{\mathrm{H}}}$, in sharp contrast to expectations from Bohr-like and classical theories. If the trend in $\sigma_{\bar{\mathrm{H}}}$ persists at high n_i, then the implications for the current experimental efforts, which aim to exploit efficient charge transfer from excited-state Ps to produce $\bar{\mathrm{H}}$, could be severe.

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