Partial-wave analysis for Ps–Xe scatterings at ultra-low energy

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We have proposed a new method to convert measured *ortho*-positronium (*o*-Ps) annihilation rates in gaseous Xe into total and differential cross sections of Ps–Xe collisions in an ultra-low-energy region of less than 80 meV where their experimental determinations as functions of Ps kinetic energy are extremely difficult [1]. Our new method makes it possible to determine not only the *s*-wave collisional parameters, *i.e.*, the scattering length and the effective range, but also the *p*- and *d*-wave parameters owing to a selection rule that *ortho-para* Ps spin-conversion annihilation is forbidden is *s*-wave scatterings. We have found a small positive value of the scattering length, $A_0 = (2.06 \pm 0.10) \times a_0$, which is similar to Xe atomic radius of $2.04\,a_0$ and is considerably smaller than Xe van der Waals radius of $4.16\,a_0$. We make an extrapolation of the analytical result into the experimentally inaccessible energy regions from 80 meV to 1.0 eV indicates that the Ramsauer–Townsend minimum should not be observed in Ps–Xe collisions because the valley is filled with the *p*- and *d*-wave contributions.

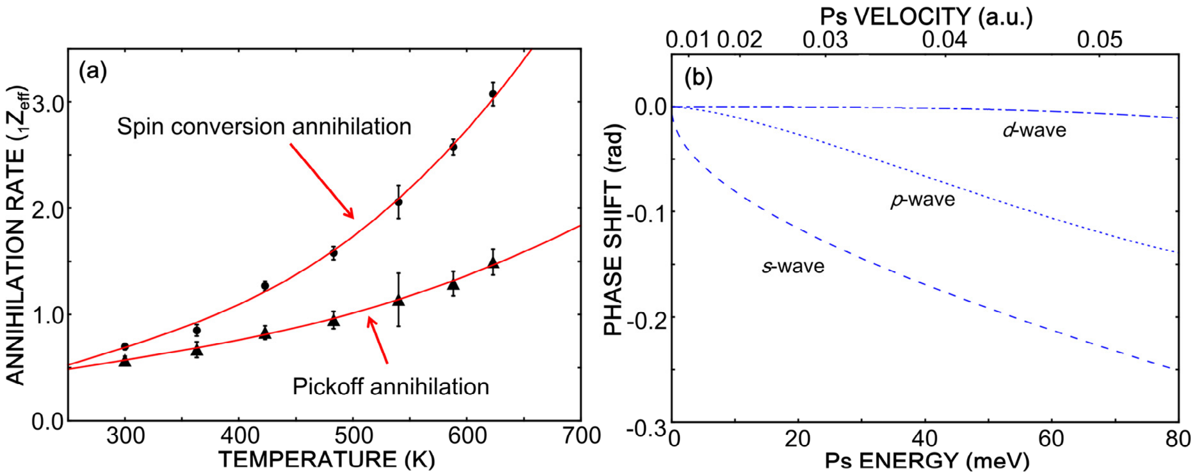

Figure (a) shows the normalized *o*-Ps annihilation rates (${}^1Z_{\mathrm{eff}}$) via two annihilation paths; one is the pickoff annihilation and the other is the self-annihilation via *ortho-para* Ps spin-conversion due to the spin-orbit interaction [1,2,3,4]. The measured points [4] are well explained as the sum of the partial-wave contributions whose phase shifts are shown in Fig. (b). The phase shifts and the annihilation rates are related as follows:

$$ {}^1Z_{\mathrm{eff}}(\text{spin convesion}) = \frac{c^3}{4\pi} f_{\mathrm{sc}} \int \rho(k) \left[\sum_{L=1}^{2} (2L+1) \sin^2 \delta_L(k) \right] k\,dk \text{ and} $$

$$ {}^1Z_{\mathrm{eff}}(\text{pickoff}) = \frac{c^3}{4\pi} f_{\mathrm{po}} \int \rho(k) \left[\sum_{L=0}^{2} (2L+1) \sin^2 \delta_L(k) \right] k\,dk, $$

where f_{sc} and f_{po} are annihilation rates per collision, k is Ps wavenumber, ρ is Ps thermal distribution (Maxwell–Boltzmann distribution), and δ_L is the phase shift at the angular momentum of L. In the case of considering complex phase shifts, $\delta_L(k) = \delta_L^{\mathrm{r}}(k) + i\delta_L^{\mathrm{i}}(k)$, will also be presented.

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