Partial-wave analysis for Positronium–Xenon collisions

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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 momentum cross sections of Ps–Xe collisions in an ultra-low-energy region where their experimental determinations as functions of Ps energy are extremely difficult [1]. Our method makes it possible to determine not only the *s*-wave parameters, *i.e.*, the scattering length and effective range, but also the *p*- and *d*-wave parameters owing to a selection rule that *ortho-para* Ps spin-conversion is forbidden in *s*-wave scatterings. We have found a small positive scattering length, $A_0 = (2.06 \pm 0.10) \cdot a_0$, which is similar to the Xe atomic radius of $2.04\,a_0$ and is considerably smaller than Xe van der Waals radius of $4.16\,a_0$.

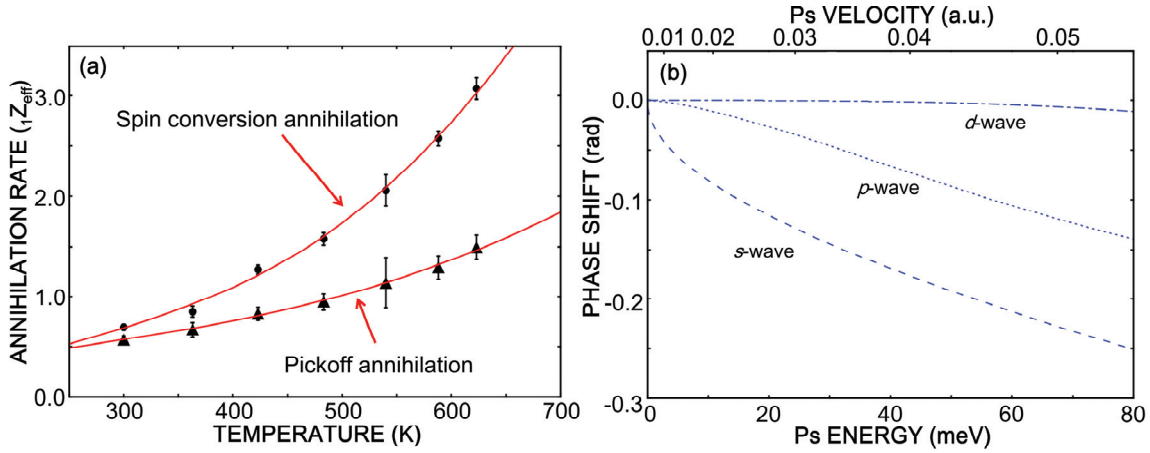
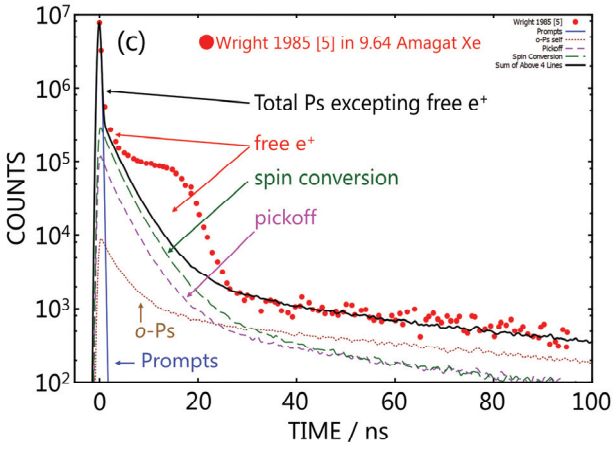


Figure (a) shows the normalized *o*-Ps annihilation rates ($^1Z_{\mathrm{eff}}$) for two paths; the pickoff annihilation and the self-annihilation via *ortho-para* Ps spin-conversion due to the spin-orbit interaction [1,2,3,4]. The measured points [4] are well explained by summing up the partial-wave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

We apply the parameters to analyse a positron lifetime spectrum in Xe by Wright et al. [5] where the positronium fraction has been estimated to be 3%. The cross sections for the pickoff annihilation and spin-conversion annihilation are described using δ_L above as $\sigma^{\mathrm{po}} = \pi K^{-2} \sum_{L=0}^{\infty} (2L+1)\left[1 - \left|S_L(K)\right|^2\right]$ and $\sigma^{\mathrm{sc}} = \pi K^{-2} \sum_{L=1}^{\infty} (2L+1)\left|1 - S_L(K)\right|^2$, where $S_L(K) = \exp[2i\delta_L(K)]$ is the *S*-matrix. We obtain the total counts of 92.1M: 20.6M Ps, 19.2M free positrons, and 50.7M other annihilations within the source and wall. The breakdown of Ps annihilation is 4.9M for *p*-Ps self-annihilation, 0.9M for *o*-Ps self-annihilation, 4.4M for the pickoff annihilation, and 10.4M for the spin conversion annihilation as shown in Fig. (c).



References [1] K. Shibuya and H. Saito, *Phys. Rev. A* **97** 052702 (2018). [2] J. Mitroy and S. A. Novikov, *Phys. Rev. Lett.* **90**, 183202 (2003). [3] H. Saito and T. Hyodo, *Phys. Rev. Lett.* **97**, 253402 (2006). [4] K. Shibuya, et al., *Phys. Rev. A* **88**, 012511 (2013). [5] G. L. Wright, et al., *J. Phys. B* **18** 4327 (1985).