Calculations of positron cooling and annihilation in noble gases

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Synopsis Positron cooling in noble gases is studied via Monte Carlo simulation and by solving the Fokker-Planck equation, using high-quality scattering and annihilation cross sections calculated from many-body theory.

Observation of lifetime spectra for positrons annihilating in a gas was one of the first sources of information on positron interaction with atoms and molecules [1]. In particular, measurements of the normalised annihilation rate $Z_{\rm eff}(t)$ during positron thermalization provided information on the energy dependence of the scattering cross sections and $Z_{\rm eff}$.

Understanding the dynamics of positron cooling, including the fraction of positrons surviving to thermalization, is critical for accurate interpretation of such experiments. Incomplete thermalization was found to be responsible for the lack of consensus among the $Z_{\rm eff}$ data in Xe [2], while modelling of $Z_{\rm eff}(t)$ [3] revealed deficiencies in the theoretical data for the heavier noble-gas atoms. Understanding of positron kinetics is also crucial for the development of efficient positron cooling in traps and accumulators [4], and for a cryogenically cooled, ultra-high-energy-resolution, trap-based positron beam [5].

Many-body theory calculations provide an accurate description of the whole body of data on low-energy positron scattering and annihilation rates on noble-gas atoms [6]. In this work we use our elastic scattering cross sections and $Z_{\rm eff}$, parameterized by Padé approximants, to study positron cooling and annihilation in noble gases via Monte Carlo simulation and numerical solution of the Fokker-Planck equation. Both methods yield the positron probability density in momentum space $f(p,t)$, which allows us to calculate $Z_{\rm eff}(t) = \int Z_{\rm eff}(p) f(p,t)dp / \int f(p,t)dp$, and γ-spectra W (wing) parameters, and compare these with experiment, where available.

For room temperature gases, we find that significant fractions of the initial positrons annihilate before thermalizing, e.g., $\sim 80\%$ in He (see Fig. 1), rising to $> 99\%$ in Xe due to the larger mass of the atom, and that in Xe, the positron lifetime is significantly increased with admixtures of He. The use of accurate atomic data leads to a better agreement with measured $Z_{\rm eff}(t)$, though we find discrepancies between measured shoulder widths of $Z_{\rm eff}(t)$, which we believe have suffered from incomplete knowledge of these fractions.

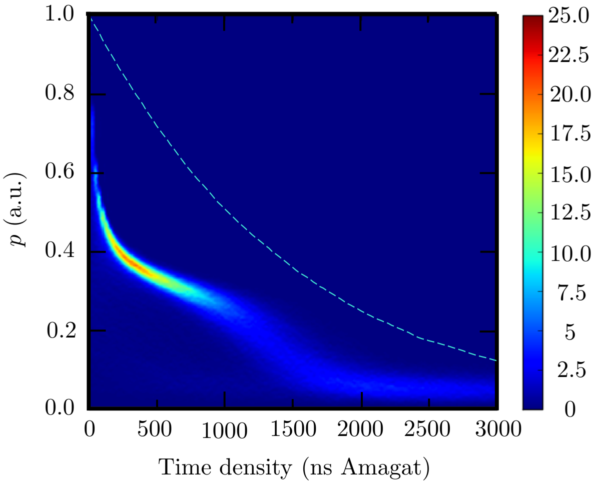

Figure 1. Momentum distribution $f(p,t)$ for positrons in helium at 293K, initially distributed uniformly in energy up to the Ps-formation threshold. The distribution is normalized as $\int f(p,t)dp = F(t)$, where $F(t)$ is the fraction of initial positrons surviving at time density t (shown as the dashed line).

References

[1] Coleman P G *et al.* 1975 *J. Phys. B* **8** 1734; Coleman P G, Griffith T C and Heyland G R 1981 *ibid.* **14** 2509

[2] Wright G L *et al.* 1985 *J. Phys. B* **18** 4327

[3] Campeanu R 1982 *Can. J. Phys.* **60** 615

[4] Al-Qaradawi I *et al.* 2000 *J. Phys. B* **33** 2725

[5] Natisin M R, Danielson J R and Surko C M 2014 *J. Phys. B* **47** 225209; Natisin M R, Danielson J R and Surko C M 2016 *Appl. Phys. Lett.* **108** 024102

[6] Green D G, Ludlow J A and Gribakin G F 2014 *Phys. Rev. A* **90**, 032712; Green D G and Gribakin G F 2015 *Phys. Rev. Lett.* **114** 093201

[7] Boyle G J *et al.* 2014 *Phys. Rev. A* **89** 022712

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