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Positronium Spin Rotation (A Research Project)

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Recently, a novel matter-probe method has been reported,[1, 2] which consists in positronium spin rotation (PsSR) in a magnetic field. It is similar to the muon spin rotation, and to the positronium (Ps) lifetime, 2-, or 3,-gamma coincidence rate and angular correlations, and the annihilation radiation energy spectrum methods used for studying matter with exotic atoms.

A spin polarized beam of positrons incident on matter may form relatively long-living Ps atoms of both spin orientations, *i.e.* both singlet and triplet states (sometimes called also para- and, respectively, ortho-positronium). A magnetic field further splits the hypefine interacting energy levels, and superpose the four spin states. The Ps gamma-decay rate depends, in principle, on this superposition, leading to well-known quantal beats. Typically, such beats appear in multiple gamma decay, like 3-gamma decay, which, in turn, is associated with the spin quadrupole moment (spin quadropolarisation). The anisotropic angular distribution of Ps decay 3-gamma quanta is measured in coincidence, exhibiting time oscillations with a frequency proportional to the magnetic field square. For a magnetic field of 1 kGs the beating frequency is about $2.5{\cdot}10^8$ Hz, comparable with detector resolution ($\sim 10^{-9}$s); however, for lower magnetic field, the beats are well resolved. Ps lifetime is cca 10^{-7} s (nearly corresponding to the triplet state, and practically unaffected by the magnetic field).

The calculations are standard and involve two main steps: the Ps 3-gamma decay amplitudes, and the spin density matrix of Ps in magnetic field. The information that can be obtained by analyzing the experimental beat decay (anisotropic, angular) cross-section is the electron spin density and dynamics in matter, the spin quadrople interaction, etc. 1-gamma cross-section in 3-gamma annihilation process exhibits similar beats.

Two problems at least remain to be further investigated. One is the calculation (and experimental detection) of polarized gamma cross-sections, a step which calls for a separate consideration, and may have an experimental relevance. Another question, towards on the theoretical side, is the investigation of the relationship of the quantum beats exhibited by PsSR and the Berry geometric phase.[3]

References

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[3] M. Berry, Proc. R. Soc. London **A392** 45 (1984).

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