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Digital spectrometer for coincidence Doppler broadening spectroscopy: application for study of positron annihilation in flight

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A novel digital coincidence Doppler broadening (DCDB) spectrometer enables to achieve an extremely low background in the spectrum. This is crucial for investigation of rare annihilation events as positron annihilation in flight or 3-gamma decay of positronium. In the present work the DCDB spectrometer was employed for investigations of annihilation in flight phenomenon using (i) monoenergetic positrons in a variable energy slow positron beam, (ii) fast positrons emitted by 68Ge/68Ga positron generator and (iii) fast positrons emitted by 44Ti/44Sc positron generator.

An energetic positron implanted into a solid matter loses rapidly its kinetic energy by elastic and inelastic collisions with electrons and reaches quickly thermal equilibrium with the surrounding medium. As a consequence positrons are annihilated predominantly in the thermalized state. However, a small fraction of positrons is annihilated before reaching the thermal equilibrium. These annihilation-in-flight events differ significantly from annihilations of thermalized positrons because in case of annihilation-in-flight events the positron momentum is significant and exceeds the momentum of electrons.

The annihilation-in-flight contribution in a two dimensional gamma ray energy spectrum fills a 'cup-like' area delimited by a hyperbolic curve imposed by the conservation of momentum and energy in the annihilation process and a 'cut-off line' corresponding to the kinetic energy of positrons. With decreasing positron energy the area of annihilation-in-flight contributions becomes smaller and smaller and finally it disappears completely for slow positrons with energies below ~100 eV. Energetic positrons are able to penetrate the Coulomb potential of the nucleus and annihilate with the deep core electrons. Hence, analysis of the outer edge of the hyperbolic annihilation-in-flight contribution in the two-dimensional energy spectrum provides information about the momentum distribution of core electrons in the target.

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