Velocity of Muonic Hydrogen Atoms after Coulomb Capture and Cascade

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The velocity of muonic hydrogen atoms Xμ (X = p, d, t) immediately after capture or during and after the end of the atomic cascade is a quantity very interesting for all kinds of experiments in muon physics:

- The velocity of Xμ while still excited influences the speed of excited-state transfer to heavier isotopes in the μCF cycle (atomic capture, transfer, muonic-molecule formation, fusion, reappearance of the muon), which may speed up this cycle considerably.
- The velocity of the Xμ in the 2s state controls the longevity of this state. At energies below a few hundred meV collision-induced transitions to the 2p state with subsequent fast deexcitation to the ground state are no longer possible. This is especially interesting for the pμ atom, where the existence of long-lived 2s states is mandatory for the feasibility of laser experiments on the 2s-2p energy difference, a very powerful tool to determine QED corrections.
- The velocity of the pμ atom in the 1s state determines to what extent nuclear capture takes place from the singlet or the triplet level of this state, respectively. At pμ kinetic energies above about 300 meV, when collision-induced singlet-triplet transitions are still possible, the two states are statistically populated. Below this energy only singlet states remain populated after a rather short transition time.

An attempt was made to measure the velocity of the pμ (dμ) system immediately after capture by a time-of-flight method. This is possible only at pressures where collision-dependent deexcitation processes like Coulomb deexcitation $[(\mathrm{X}\mu)_n + \mathrm{H}_2(\mathrm{D}_2) \Rightarrow (\mathrm{X}\mu)_{n-1} + \mathrm{H}_2(\mathrm{D}_2)$, with n the principal quantum number] and Auger effect or deceleration processes like elastic collisions are rare enough not to change the velocity of the muonic atom during its flight path. Rough estimates showed that at pressures below 0.1 hPa these prerequisites for a reliable measurement are met.

Experimental set-up and measuring method have been described earlier [1]. Low-energy muons are stopped on the axis of a cylindrical low-pressure gas target with thin windows and the time between μ stop and arrival of the pμ atom at the walls are registered: immediately after the pμ system hits the gold-coated target wall the muon is transferred to gold and muonic x rays from gold are emitted. All this happens in a strong axial magnetic field which keeps the muons on the right track but does not affect the (neutral) pμ system. The pμ energy distribution for a cylindrical target at a pressure of only 0.062 hPa (roughly 1/1000 of the lowest pressures at which measurements were performed up to now) is shown in Fig. 1. The result is highly preliminary. Nevertheless it shows that the mean pμ kinetic energy is well below 1 eV. At higher pressures processes changing the pμ kinetic energy become more and more important. A remarkable result of the measurement is that already at 1 hPa the mean kinetic energy has increased drastically to (2.6 ± 0.6) eV, apparently due to acceleration by Coulomb deexcitation. A careful evaluation of all data (taken also at 0.25, 4, 16 and 64 hPa) will, without doubt, allow to thoroughly test the models for capture, collisions and cascade in the pμ(dμ) atom.

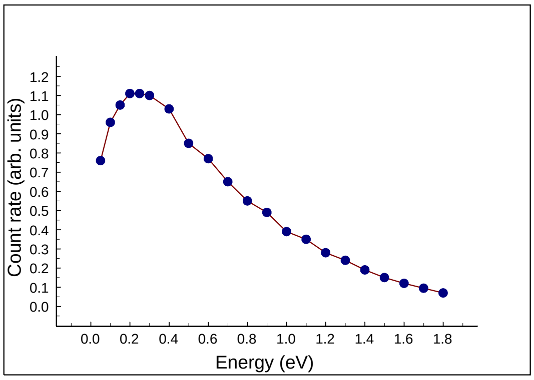

Fig. 1: Kinetic-energy distribution of pμ atoms generated in hydrogen gas at a pressure of 0.062 hPa.

References

[1] F. J. Hartmann *et al.*, Hyp. Int. **101/102** (1996) 623