Kinetic Energy Distribution of the μp(1s) Atoms as Function of Density

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An experiment making use of the low energy μ^- beam produced at Paul Scherrer Institute provided for the first time the kinetic energy distribution of μp atoms. This information is relevant for experiments in preparation at PSI on two fundamental quantities, the 1s width of the πp atom [1] and the Lamb shift of the μp atom [2].

In a cylindrical target (length about 20 cm) with low density hydrogen axial injection of the low energy μ^- beam results in a pencil–like stopping volume. The formed μp atoms travel to the gold–coated inner cylinder wall. Their time-of-flight distribution is measured by detecting the x rays emitted after the transfer reaction of μp atoms with Au. In the cylindrical geometry a large fraction of the μp atoms reach the wall after a path which is only slightly longer than the path perpendicular to the axis. This results in a good velocity resolution allowing to deduce the energy distribution of the μp atoms. Consistency checks can be performed by using variable inner wall diameters. Information on elastic cross-section of the μp(1s) on H_2 can be deduced from the higher-density targets.

Measurements done previously with inner wall diameters of 20 and 58 mm have been recently extended to smaller diameters (7 and 12 mm) providing a higher sensitivity to energies $T_{\mu p} \leq 0.5$ eV. A detailed data analysis allowed to determine the background contribution from muon decay electrons in a self-consistent and reliable way. Fig. 1 shows the kinetic energy distribution obtained at the lowest pressure (1/16 hPa at room temperature) and at 16 hPa (here the targets with small inner diameter have been used).

Information on the atomic formation of exotic hydrogen atoms which takes place at high excitation levels n is obtained here for the first time. Pressures below 0.1 hPa are required to ensure that at least part of the formed μp atoms deexcite without collisions. The observed energy distribution and its pressure dependence allow to deduce the range of n levels initially populated. At 16 hPa the kinetic energy distribution extends to quite high values (15% with $T_{\mu p} > 10$ eV). This indicates a strong acceleration of the μp atom that can only be reached by Coulomb deexcitation involving relatively low n levels. The deduced strength of the interaction is much larger than predicted by calculations [3] done with H-atoms as collision partners.

The results (see table 1) are sufficiently precise to provide essential conclusions on the fraction of metastable μp(2s) as function of density. The initial μp(2s) kinetic-energy distribution is practically identical to the one of μp(1s). Metastable μp(2s) are formed when the μp(2s) are slowed down to below 0.31 eV. Table 1 gives the expected metastable 2s fraction f based on a calculation of the μp(2s) slowing down and quenching [4]. The last line gives a lower limit corresponding to $T_{\mu p(2s)} \leq 0.30$ eV.

	1/16 hPa	16 hPa
$T_{\mu p} \leq 0.5$ eV	0.48 ± 0.08	0.17 ± 0.02
$T_{\mu p} \leq 1.0$ eV	0.70 ± 0.06	0.30 ± 0.03
$T_{\mu p} \leq 2.0$ eV	0.79 ± 0.04	0.47 ± 0.03
f(expected)	0.70 ± 0.10	0.25 ± 0.05
f(lower limit)	0.30	0.09

Table 1: Fraction of μp atoms with kinetic energies $T_{\mu p} \leq T$ and metastable 2s fraction f.

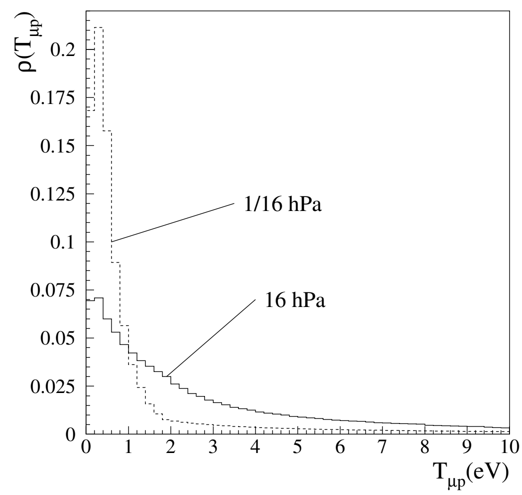

Fig. 1: Density distribution $\rho(T_{\mu p})$ of kinetic energies of the μp atom at 1/16 hPa and 16 hPa H_2 gas pressure.

References

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