Investigation of the $\mu p\,(2s)$ Metastability

T. W. Hänsch [a], F. J. Hartmann, P. Hauser [b], F. Kottmann [c], C. Petitjean, R. Pohl, W. Schott, and D. Taqqu [b]

[a] Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany
[b] Paul Scherrer Institut, CH-5232 Villigen, Switzerland
[c] Institut für Hochenergiephysik, Eidgen. Techn. Hochschule Zürich, CH-8093 Zürich, Switzerland

The availability of metastable $\mu p\,(2s)$ is a prerequisite for the realisation of the laser spectroscopy measurement of the $2s$-$2p$ splitting (Lamb Shift) in the μp atom [1] . A previous measurement of the kinetic energy distribution of the μp atoms already indicated that by lowering the target pressure to much less than a mbar the kinetic energy of the μp atoms falls down to such low values ($E_{kin} < 1\,eV$) [2] that a metastable $2s$ fraction exceeding 40% can be obtained. However, as the spectroscopy measurement is optimally done at pressures greater than 1 mbar where most μp's have been found to be quite fast ($E_{kin} > 1\,\mathrm{eV}$), we developed a novel technique that should allow us to directly determine the $2s$ metastable fraction as a function of pressure. It makes use of the transfer reaction which allows the detection of the $\mu p\,(2s)$ via the μZ X-rays emitted after a collision with an atom of charge Z. Delayed X-rays can only arise either from metastable $\mu p\,(2s)$ or from $\mu p\,(1s)$ which, although formed a few hundred times more frequently, have their contribution strongly inhibited if one uses:

1. a Z-atom for which the transfer rate from $\mu p\,(1s)$ has been measured to be quite low. Most suitable is Neon for which recent measurements [3] give a $1s$ transfer rate $\lambda_{1s} = 5.1 \cdot 10^{-3}\,s^{-1}$ at 1 mbar while the transfer rate λ_{2s} for thermalized $\mu p\,(2s)$ is expected to be 200 times higher.

2. a cylindrical target with a small diameter (1.5 cm for a stopping volume of 1 cm diameter). The $\mu p\,(1s)$ atoms have such a small collision cross-section that they go straight into the target walls within a few 100 ns. In contrast, the metastable $\mu p\,(2s)$ atoms which thermalize quickly are slow and have such a large diffusion cross-section that they practically never reach the walls.

First measurements confirmed the validity of the concept. Figure 1 shows the time distribution of the Neon X-rays obtained at 4 mbar in a H_2+25% Ne target. A small background contribution has been substracted on the basis of a measurement done in pure H_2. The prompt peak is due to the direct formation of μNe together with some fast μp transfer during the cascade. As a result μNe is formed 1.5 ± 0.2 times more frequently than $\mu p\,(1s)$. The peak shape is determined by the spread in stopping time for our muon beam of very low energy($\sim 10\,\mathrm{k}eV$). The delayed events are due to transfer from either $\mu p\,(1s)$ or metastable $\mu p\,(2s)$. The given calculated $\mu p\,(1s)$ time distribution has its amplitude fixed by the measured λ_{1s} [3] and its shape determined by a Monte-Carlo simulation of the $\mu p\,(1s)$ disappearance in the target walls. With its precision level of about 20% it falls by far below the measured delayed transfer signal. (No such delayed signal is observed in a Helium + 25% Neon target).

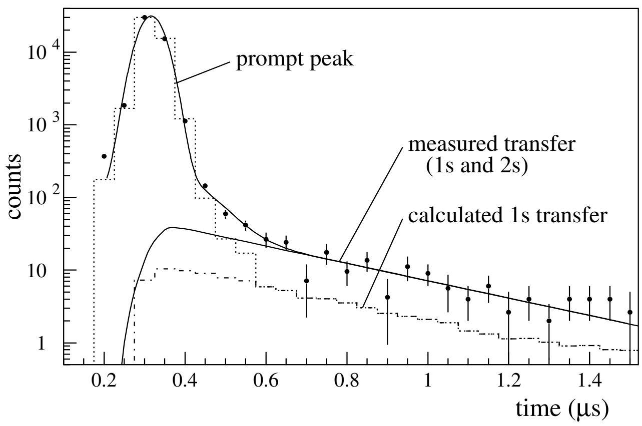

Fig. 1: Measured neon X-ray signal (solid dots). The solid lines are a fit of the measured prompt peak and a delayed transfer signal. The Monte Carlo simulation using the calculated value for the 1s transfer is also shown.

Two effects can be invoked to explain the excess delayed transfer signal. First, naturally the transfer from metastable $\mu p\,(2s)$ and second a possible significant increase of the $1s$ transfer rate with μp kinetic energy. (Ref. [3] measures at $E_{\mathrm{kin}} < 0.5\,\mathrm{eV}$, while our $\mu p\,(1s)$ atoms have predominantly $E_{\mathrm{kin}} > 1\,\mathrm{eV}$). In order to specifically distinguish the metastable $2s$ contribution, λ_{2s} is varied by changing the neon concentration: the decay time of the $2s$ transfer signal varies then as $1/\,(\lambda_{2s} + \lambda_\mu)$ while the shape of the $\mu p\,(1s)$ transfer curve remains unaffected. Such measurements, done so far with limited statistics, give a clear indication of some 2s transfer, a first direct sign of the existence of metastable $\mu p\,(2s)$. Extended measurements, planned for this year, will provide a precise value for the metastable 2s fraction.

References

[1] D. Taqqu *et al.*, Hyp. Int. **101/102** (1996) 599

[2] F.J. Hartmann *et al.*, PSI Nuclear and Particle Physics, Newsletter (1996) 31

[3] R. Jacod-Guillarmod *et al.*, Phys. Rev. **A51** (995) 2179