PSI Results from Hadronic Atoms

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In pionic hydrogen (πH) the hadronic interaction manifests itself by a change of the energies and of the natural line width of K X–rays as compared to a purely electromagnetically bound atomic system. Measurement of ground–state transitions allows the determination of the πN s–wave interaction, which is described by the isoscalar and isovector scattering lengths a^+ and a^- [1, 2, 3]. In addition, from the line broadening Γ_{1s}, which depends only on a^-, the πN coupling constant can be extracted by the Goldhaber–Miyazawa–Ohme sum rule [4].

To improve on the accuracy achieved by previous measurements [5], a thorough study of the atomic cascade is essential. For that purpose, a first series of measurements has been completed by the new pionic–hydrogen experiment at the Paul–Scherrer–Institut (PSI R–98.01 [6]), using the new cyclotron trap, a cryogenic target, a Bragg spectrometer equipped with spherically bent silicon and quartz crystals and a large–area CCD array. Data analysis is in progress.

Except radiative decay, de–excitation during the atomic cascade is due to collisions of the πH system with other atoms of the target, which leads to density effects because of different collision probabilities. In order to identify radiative de–excitation of the πH atom – when bound into complex molecules formed during collisions $\pi^- p + H_2 \longrightarrow [(pp\pi^-)p]ee$ [7] – the energy of the πH(3p-1s) transition was measured at various target densities corresponding to a pressure range from 3.5 bar to liquid. X–ray transitions from molecular states should then show up as low–energy satellites with density dependent intensity. The new data do not show any density effect and, consequently, the measured line shift ϵ_{1s} can be attributed exclusively to the strong interaction. The value of $\epsilon_{1s} = 7.120 \pm 0.013\,\mathrm{eV}$ was found to be in good agreement with the result of the previous experiment. Precision was improved by more than a factor of two [8, 9].

At present, the accuracy for Γ_{1s} (7%) is limited by the not sufficiently well known correction for the Doppler broadening of the X–ray lines [5]. The broadening is caused by conversion of de–excitation energy into kinetic energy during collisions (Coulomb de–excitation) [10]. For that reason the precisely measured 1s–level shift in pionic deuterium was used together with the shift of hydrogen in the determination of the πN scattering lengths [11]. This procedure, however, requires a sophisticated treatment of the 3–body system πD. In addition, up to now it cannot be excluded that the radiative decay channel after molecule formation is strongly enhanced in deuterium compared to hydrogen.

To study the influence of Coulomb de–excitation on the cascade, the three transitions πH(2p-1s) (2.4 keV), πH(3p-1s) (2.9 keV) and πH(4p-1s) (3.0 keV) were studied at a target density equivalent to 10 bar. An increase of the line width was found for the (2p-1s) line compared to the (3p-1s) transition, which is attributed to the higher energy release available for the acceleration of the πH system. This result is corroborated by a reduced line width of the (4p-1s) transition [8, 9]. The response of the crystal spectrometer was obtained here from the π^{12}C(5g-4f) line (3.0 keV), which is negligibly narrow compared to the experimental resolution. From the (4p-1s) line width, a safe upper limit for the 1s–level broadening of $\Gamma_{1s} < 850\,\mathrm{meV}$ is extracted, which is smaller than the result of [5] but still consistent within the errors.

For further improvement, Coulomb de–excitation must be studied in more detail. For this reason a second series of measurements is foreseen starting with a high statistics study of ground–state transitions from muonic hydrogen (μH), where no strong–interaction effects occur. Beforehand, the crystal resolution function, which has to be known with better accuracy than available from a πC spectrum, will be determined with X–rays emitted from helium–like argon, ionised by means of an electron–cyclotron resonance ion trap (ECRIT) presently set up at PSI [13]. With that, studies of the Bragg crystals can be performed with the neccessary statistics within a reasonable time scale. The μH experiment will then be followed by a remeasurement of πH with high statistics.

With the detailed knowledge of the crystal response together with a newly developed cascade code [12], which includes the velocity development during the atomic cascade, a sufficiently accurate correction for the Doppler broadening in pionic hydrogen should be achievable to extract Γ_{1s} at the level of about 1%.

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