Long-lived atomic and nuclear states explored using dielectronic recombination

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Long-lived atomic or nuclear states are fascinating candidates for investigation and improving our understanding of transition dynamics. The hindered decay modes of metastable species are often accompanied by exotic decay pathways and/or higher order or multi-photon transitions. As a consequence of long lifetimes and extraordinary decay properties, nuclear isomers as well as atomic metastable ions play an important role in astrophysics, for precision spectroscopy, for the study of fundamental symmetries, for energy storage or —based on their small natural widths— for applications as clocks.

Storage rings provide a very clean environment with well-controlled experimental conditions for the investigation of long-lived species. Our approach for studying metastable states exploits the unique properties of the resonant process of dielectronic recombination (DR) as a spectroscopic tool. DR resonance spectra feature unique signatures associated with the long-lived excited states. Atomic metastable states show up in the DR pattern as new resonance series that originate from the initially metastable configurations. Nuclear isomeric states exhibit resonance fingerprints in the DR spectra mainly due to the distinctively different hyperfine interaction and nuclear size shifts of nuclear ground and isomeric states. In the last two years, our collaboration at the ESR storage ring has achieved substantial progress in the investigation of both, atomic and nuclear metastable states applying the DR resonance technique.

(1) Measurements with beryllium-like 138Xe50+ ions were carried out that revealed resonances that could be clearly attributed to initially metastable Xe50+ (2s2p3P0) ions. In Be-like ions, in the absence of nuclear spin the 3P0-state can only decay via a E1M1 double-photon or even higher order multi-photon transitions [1]. By monitoring the intensity of resonance configurations associated with the 3P0 state at time intervals 50 s apart from each other the existence of a decaying beam admixture, i.e. the metastable component was directly proven [2]. At present, the influence of unwanted effects on the decay time such as quenching of the level in the residual gas or in the magnetic fields of the ring magnets is being evaluated. As the next step, a dedicated lifetime measurement of this sought-after transition is envisaged.

(2) A pilot experiment that leveraged the DR technique for the study of nuclear isomers was successfully performed with Li-like 234mPa88+. Its isomeric state (Iπ = 0+) possesses no hyperfine splitting and decays within 1.17 min predominantly (99.84 %) due to β−-emission [3]. The Iπ = 4+ ground state features hyperfine splitting and decays substantially slower (τ = 6.7 h). The fast β−-decay provides an independent way to monitor the intensity of the isomer. In our DR experiment we measured an initial resonance spectrum of 234m(m′)Pa88+ about 30 s after beam injection, i.e., with a mixture of ground and isomeric state ions. A second data set was taken after 5 min of waiting when the isomers are expected to have completely decayed, thus resulting in a ground-state-only spectrum. Consequently, by comparison of the two data sets the DR spectrum of a nucleus in its isomeric state can be deduced.

(3) 235mU is a particularly interesting nuclear isomeric state with an excitation energy as low as 76.8 eV [3]. In a preparation experiment in October 2011 we managed to produce a pure isomeric beam of Li-like 235mU89+ ions by accumulation of β−-decay daughters of 235Pa parent ions in the storage ring. With roughly 200 ions produced every 20 mins we could perform meaningful DR experiments. The measurement highlights the sensitivity and the versatility of the combination of storage ring and the DR method. It is worth emphasizing that in contrast to Schottky techniques the DR approach is also possible for low excitation energies and thus provides access to such intriguing candidates as 235mU or the famous “nuclear clock” isotope 229Th [3].

These initial results on DR experiments that explore atomic and nuclear metastable states are very promising for future extensions of this method. In particular, in combination with stochastic cooling storage times of hours up to days can be achieved. This enables studies with very long-lived candidates using the DR pattern as an intensity signature. Support is acknowledged by BMBF under contract number 06 GI 9111 and by the Alliance Program of the Helmholtz Association (HA216/EMMI).

References