QED tests of heliumlike systems with X-ray laser spectroscopy

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Emission spectroscopy in electron beam ion traps has been the main tool for precision studies of highly charged ions (HCI), delivering essential data on their level structure and, in a few instances, also on the related transition probabilities. Its essential limitation arises from the unavoidable compromise between achievable resolution and signal strength in the observation of isotropically emitting sources. This shortcoming is circumvented, much like in optical laser spectroscopy, by the recently introduced method of resonant fluorescence spectroscopy of HCI at highly collimated X-ray sources, such as synchrotrons and free-electron lasers. Here, the advantages of the large linear photon energy dispersion achievable with very large monochromators, and the high spectral purity of the sources due to the use of insertion devices, allow one to reach a resolution akin to the highest ones reported in emission spectroscopy works but with much shorter data acquisition times.

Our experimental investigations on the oscillator strengths of the most intense L-shell transitions of Fe^{16+} at around 800 eV [1] using the free-electron laser LCLS have led to a better understanding of a long-standing astrophysical controversy. Furthermore, using highly monochromatized synchrotron radiation from PETRA III we have also resonantly excited the ions $Fe^{18+..24+}$ [2] and Kr^{34+} at photon energies around 6.6 keV and 13.1 keV, respectively, with substantially improved accuracy. These results strongly support state-of-the-art QED calculations of two-electron systems [3], which had recently been contested [4]. Moreover, the achieved resolution was sufficient for determining the natural line widths of several Kα? transitions in Fe ions for the first time. Such X-ray lines are the underlying spectral constituents of the relativistically broadened and shifted fluorescence features observed in active galactic nuclei with central massive black holes, and in their jets. Modelling such astrophysical spectra, and those of future missions like *Athena+*, will require improved and benchmarked atomic physics input data.

Further enhancements of our method will include the use of higher-resolving monochromators and free-electron lasers seeding schemes, as well as the linkage of HCI transitions to Mößbauer nuclear transitions and metrological wavelength standards. We are currently testing the long sought-after [5] sympathetic cooling of HCI in our novel cryogenic Paul trap CryPTEx [6] using Be^+ ion Coulomb crystals to lower the ion temperature by a factor of more than one million. In combination with various improved fluorescence detection schemes based on photon recoil [7], we expect further enhancements of the current experimental capabilities. In this way, more stringent tests of the QED calculations in fundamental systems such as hydrogenlike and heliumlike ions will become possible. In the long run, direct frequency determinations in the X-ray region could provide new insights in the physics of those strong-field QED systems.

References

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