Strong Field Physics

Thomas Stöhlker[1,2,3], Stephan Fritzsche[1,2,3], Alexandre Gumberidze[3], Yury A. Litvinov[3], Gerhard Paulus[1,2], Wolfgang Quint[3], Wilfried Nörtershäuser[4], Vladimir Shabaev[5], Ingo Uschmann[1,2], Andrey Volotka[1,2,3],

[1]*Helmholtz-Institut Jena, D-07743 Jena, Germany*
[2]*IOQ, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany*
[3]*GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany*
[4]*Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany*
[5]*Department of Physics, St. Petersburg State University, 7/9 Universitetskaya naberezhnaya, St. Petersburg 199034, Russia*

Highly charged ions (HCI) combine extremely strong electromagnetic fields and a simple electronic structure which makes them an ideal testing ground for fundamental theories such as quantum mechanics, relativity and quantum electrodynamics (QED) in the domain of the strongest electromagnetic fields available for experimental investigations. In this tutorial, an overview of the recent progress in demanding experiments aiming at the investigation of QED in such strong and even critical fields will be given. In addition, we will address experimental studies with HCI of dynamic and non-linear processes in the strong-field limit and at femto- and sub-femtosecond time scales, such as fundamental scattering and impact phenomena for electrons as well as for photons. We will also elucidate a complementary research activity, namely the investigations of the vacuum birefringence, where the vacuum is excited by the presence of an intense laser (electro-magnetic) field.

More specifically, the tutorial will concentrate on the status of experiments exploiting the unique opportunities provided by storage and trapping facilities for ions at high-Z (Electron Beam Ion Traps, Penning Traps, and Storage Rings) as well as by strong field laser facilities (XFEL and high-power lasers) [1,2]. Particular emphasis will be given to measurements of the magnetic moments (g-factors), providing the most accurate determination of the electron mass [3], the hyperfine splittings in Bi^{82+} and Bi^{80+} ions, revealing a substantial deviation from QED predictions [4], and a very recent result for the 1s Lamb-Shift of Au^{78+} [5]. In addition, atomic processes related to ultrafast electromagnetic interactions will be addressed, which are used to explore correlation and relativistic effects in bound few-electron systems. Complementary, attention will be given to unique opportunities provided by XFEL facilities in combination with intense electro-magnetic fields as provided by high-power lasers to observe, for the very first time, vacuum birefringence in photon-photon collisions [6].

Finally, the relevance of strong field physics will be discussed with a particular focus on the intersection of atomic, nuclear, and plasma physics which is essential for our understanding of astrophysical processes, a research field where the future FAIR facility will provide unique research opportunities [1]. Examples are rare nuclear decay modes, only possible in highly ionized, exotic atoms [7].

[1] Stöhlker T *et al* 2015 *Nucl. Instr. Meth. Phys. Res. B* **365** 680-685
[2] Tschentscher T *et al* 2107 *Appl. Sci.* **7** 592
[3] Sturm S *et al* 2014 *Nature* **506** 467
[4] Ullmann J *et al* 2017 *Nature Comm.* **8** 15484
[5] Gassner T *et al* 2018 *New J. Phys.* **20** 073033
[6] Heinzel T *et al* 2006 *Opt. Comm.* **267** 318; Karbstein F *Phys. Rev. D* **98** 056010
[7] Bosch F *et al* 2013 *Prog. Part. Nucl. Phys.* **73** 84